

**Technology Profiles**  
**Eleventh Edition**

**Volume 2**  
**Emerging Technology Program**

**National Risk Management Research Laboratory  
Office of Research and Development  
U.S. Environmental Protection Agency  
Cincinnati, Ohio 45268**

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## **NOTICE**

The development of this document was funded by the U.S. Environmental Protection Agency (EPA) under Contract No. 68-W-01-032, Task Order 14, to Computer Sciences Corporation. The document was subjected to the Agency's administrative and peer review and was approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use at any particular hazardous waste site.

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## FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threatens human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions, and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by the EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Hugh W. McKinnon, Director  
National Risk Management Research Laboratory

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## ABSTRACT

The Superfund Innovative Technology Evaluation (SITE) Program, now in its sixteenth year is an integral part of EPA's research into alternative cleanup methods for hazardous waste sites around the nation. The SITE Program was created to encourage the development and routine use of innovative treatment and monitoring and measurement technologies. Under the program, EPA enters into cooperative agreements with technology developers. These developers research and refine their innovative technologies at bench- or pilot-scale and then, with EPA's support, demonstrate them at hazardous waste sites. As a result, the SITE Program provides environmental decision-makers with data on new, viable treatment technologies that may have performance or cost advantages compared to traditional treatment technologies.

This document is intended as a reference guide for those interested in technologies participating in the SITE Demonstration, Emerging Technology, and Measurement and Monitoring Programs. The two-page profiles are organized into two sections for each program, completed and ongoing projects, and are presented in alphabetical order by developer name. Reference tables for SITE Program participants precede the sections and contain EPA and developer contacts. Inquiries about a SITE technology evaluation or the SITE Program should be directed to the specific EPA project manager; inquiries on the technology process should be directed to the specific technology developer.

Each technology profile contains (1) a technology developer and process name, (2) a technology description, including a schematic diagram or photograph of the process, (3) a discussion of waste applicability, (4) a project status report, and (5) EPA project manager and technology developer contacts. The profiles also include summaries of demonstration results, if available. The technology description and waste applicability sections are written by the developer. EPA prepares the status and demonstration results sections.

A Trade Name Index and Applicability Index are also included in the back of this document. The Applicability Index is organized by 11 media categories, 19 waste categories, and 14 technology categories.

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## **ACKNOWLEDGMENTS**

The project manager responsible for the preparation of this document is Teri Richardson of EPA's National Risk Management Research Laboratory in Cincinnati, Ohio. This document was prepared under the direction of Robert Olexsey, Director of the Land Remediation and Pollution Control Division. Key program area contributors for EPA include Annette Gatchett, and Randy Parker. Special acknowledgment is given to the individual EPA SITE project managers and technology developers who provided guidance and technical support.

Computer Sciences Corporation prepared this document under the direction and coordination of Teri Richardson and Annette Gatchett.

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## SITE PROGRAM DESCRIPTION

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The U.S. Environmental Protection Agency's (EPA) Superfund Innovative Technology Evaluation (SITE) Program, now in its sixteenth year, encourages the development and implementation of (1) innovative treatment technologies for hazardous waste site remediation, and (2) characterization and monitoring technologies for evaluating the nature and extent of hazardous waste site contamination.

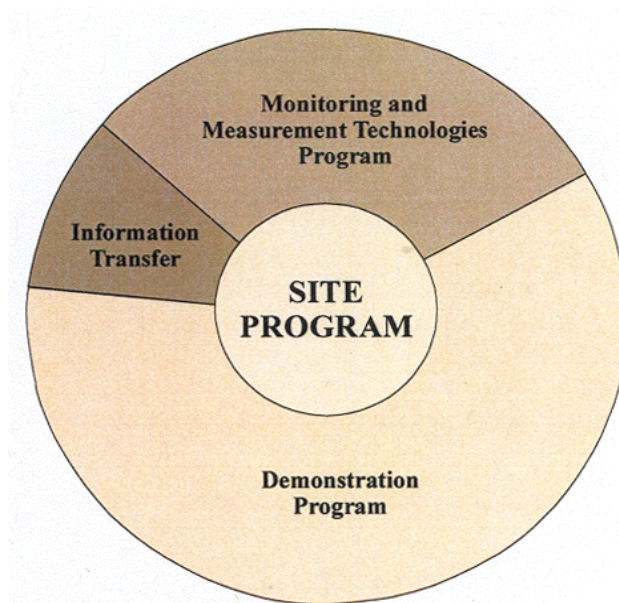
The SITE Program was established by EPA's Office of Solid Waste and Emergency Response (OSWER) and the Office of Research and Development (ORD) in response to the 1986 Superfund Amendments and Reauthorization Act (SARA), which recognized a need for an "Alternative or Innovative Treatment Technology Research and Demonstration Program." The SITE Program is administered by ORD's National Risk Management Research Laboratory (NRMRL), headquartered in Cincinnati, Ohio.

The SITE Program includes the following key elements:

- **Demonstration Program** - Conducts and evaluates demonstrations of promising innovative technologies to provide reliable performance, cost, and applicability information for site cleanup decision-making
- **Emerging Technology Program** - Support of the Emerging Technology Program ended in 1998 after completion of all committed projects in the Program
- **Monitoring and Measurement Technologies** - Evaluates technologies that detect, monitor, and measure hazardous and toxic substances to provide better, faster, and more cost-effective methods for producing real-time data during site characterization and remediation
- **Information Transfer Activities** - Disseminates technical information, including engineering, performance, and cost data, on innovative technologies to remove impediments for using innovative technologies

This Technology Profiles document describes completed and ongoing projects in the Demonstration, Emerging Technology, and Characterization and Monitoring Programs. Figure 1 shows the relationship among the programs and depicts the process of technology development from initial concept to commercial use.

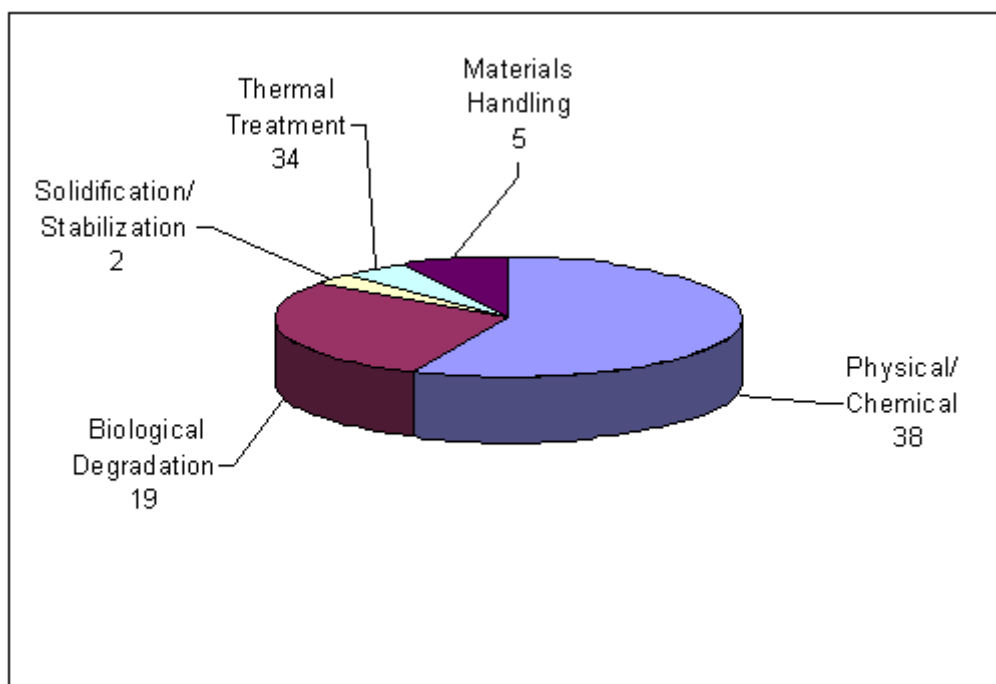
In the Demonstration Program, the technology is field-tested on hazardous waste materials. Engineering and cost data are gathered on the innovative technology so that potential users can assess the technology's applicability to a particular site. Data collected during the field demonstration are used to assess the performance of the technology, the potential need for pre- and post-processing of the waste, applicable types of wastes and waste matrices, potential operating problems, and approximate capital and operating costs.



**Figure 1** *Development of Innovative Technologies*

At the conclusion of a SITE demonstration, EPA prepares an Innovative Technology Evaluation Report (ITER), Technology Capsule, and Demonstration Bulletin. Often, a videotape of the demonstration is also prepared. These reports evaluate all available information on the technology and analyze its overall applicability to other site characteristics, waste types, and waste matrices. Testing procedures, performance and cost data, and quality assurance and quality control standards are also presented. These demonstration documents are distributed by EPA to provide reliable technical data for environmental decision-making and to promote the technology's commercial use.

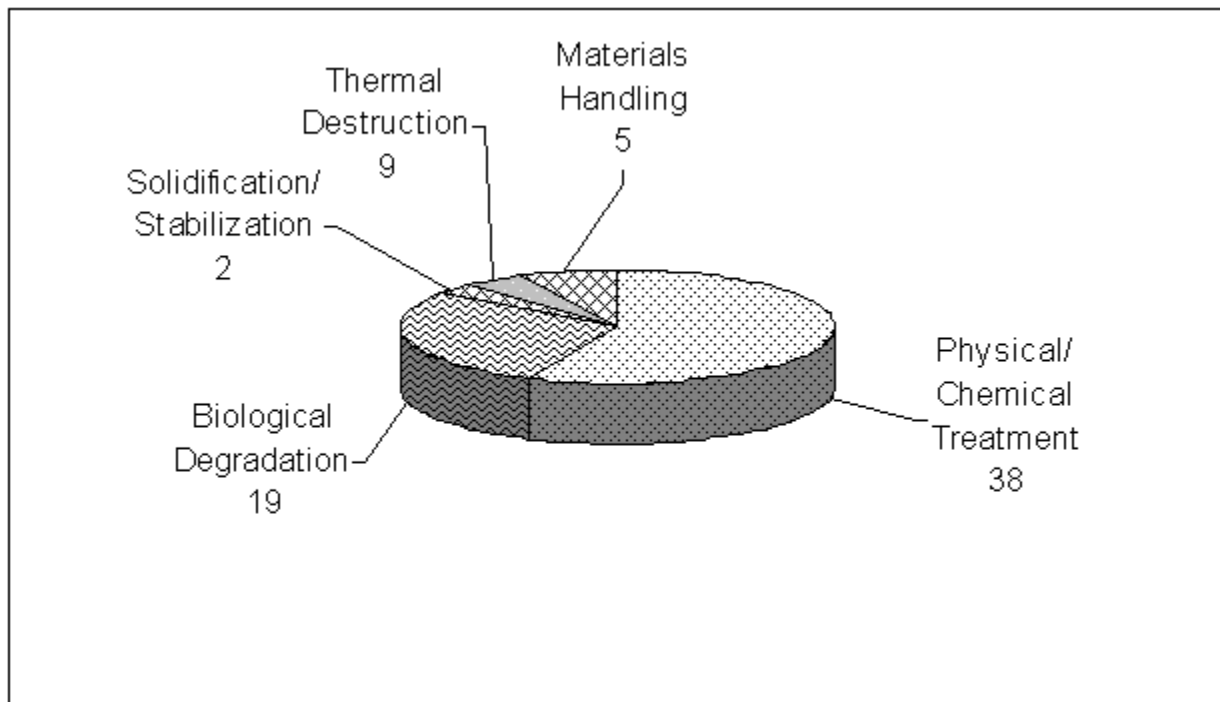
The Demonstration Program currently has 147 program participants conducting 141 demonstrations. Of these projects 128 demonstrations are complete and 13 are ongoing. The projects are divided into the following categories: thermal treatment (34), biological degradation (28), physical/chemical treatment (50), solidification/stabilization (13), phytoremediation (5), soil washing (4), materials handling (3), and other (4). Several technologies represent more than one treatment category.



**Figure 2:** *Innovative Technologies in the Emerging Technology Program*

Figure 2 shows the breakdown of technologies in the Demonstration Program. Profiles for technologies demonstrated under the Demonstration Program are located in Volume I.

EPA has provided technical and financial support to 77 projects in the Emerging Technology Program. Seventy-three are completed and four have exited the program. Eighteen Emerging Technology Program projects participated in the Demonstration Program. The seventh-three active technologies are divided into the following categories: thermal destruction (9), physical/chemical treatment (38), biological degradation (19), solidification/stabilization (2), and materials handling (5). Figure 3 displays the breakdown of technologies in the Emerging Technology Program. Profiles for technologies demonstrated under the Emerging Technology Program are located in Volume II.



**Figure 3:** Innovative Technologies in the Demonstration Program

The Monitoring and Measurement Technologies (MMT) Program's goal is to assess innovative and alternative monitoring, measurement, and site characterization technologies. To date, 38 technology demonstrations have occurred under the MMT Program. These demonstrations have included four cone penetrometers, 6 field portable X-ray fluorescence units, 6 portable gas chromatographs, 4 spectrophotometers, 12 field test kits, and 6 soil samplers. Profiles for technologies demonstrated under the MMT Program are located in Volume III.

In the Technology Transfer Program, technical information on innovative technologies in the Demonstration Program, Emerging Technology Program, and MMT Program is disseminated to increase the awareness and promote the use of innovative technologies for assessment and remediation at Superfund sites. The goal of technology transfer activities is to promote communication among individuals requiring current technical information for conducting site investigations and cleanups.

The Technology Transfer Program reaches the environmental community through many media, including:

- Program-specific regional, state, and industry brochures
- On-site Visitors' Days during SITE demonstrations
- Demonstration videotapes
- Project-specific fact sheets to comply with site community relations plans
- ITERs, Demonstration Bulletins, Technology Capsules, and Project Summaries

- 
- The SITE Exhibit, displayed nationwide and internationally at conferences
  - Networking through forums, associations, regions, and states
  - Technical assistance to regions, states, and remediation cleanup contractors

SITE information including an electronic version of this document, is available through the following on-line information clearinghouses:

SITE Program Home Page: <http://www.epa.gov/ORD/SITE>

Cleanup Information Bulletin Board System (CLU-IN)

Help Desk: 301-589-8368; Internet Access: <http://www.clu-in.org>

Technical reports may be obtained by calling the National Service Center for Environmental Publications in Cincinnati, Ohio. To find out about newly published documents or to be placed on the SITE mailing list, call or write to:

USEPA/NSCEP  
P. O. Box 42419  
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## SITE PROGRAM CONTACTS

The SITE Program is administered by EPA's Office of Research and Development (ORD), specifically the National Risk Management Research Laboratory (NRMRL). For further information on the SITE Program or its component programs contact:

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**ACTIVE ENVIRONMENTAL TECHNOLOGIES, INC.**  
(formerly EET, Inc.)  
(TechXtract® Decontamination Process)

**TECHNOLOGY DESCRIPTION:**

The TechXtract® process employs proprietary chemical formulations in successive steps to remove polychlorinated biphenyls (PCB), toxic hydrocarbons, heavy metals, and radionuclides from the subsurface of porous materials such as concrete, brick, steel, and wood. Each formulation consists of chemicals from up to 14 separate chemical groups, and formulation can be specifically tailored to individual site.

The process is performed in multiple cycles. Each cycle consists of three stages: surface preparation, extraction, and rinsing. Each stage employs a specific chemical mix.

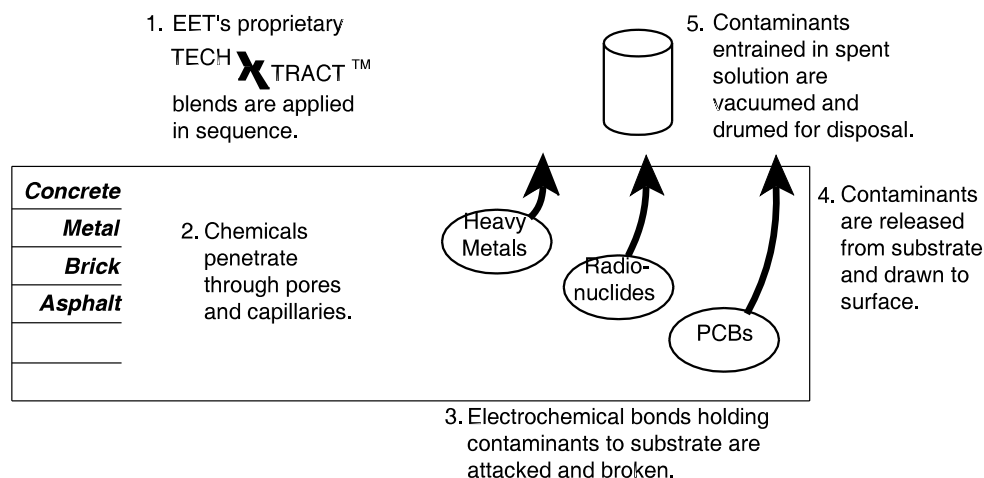
The surface preparation step uses a solution that contains buffered organic and inorganic acids, sequestering agents, wetting agents, and special hydrotrope chemicals. The extraction formula includes macro- and microemulsifiers in addition to electrolyte, flotation, wetting, and sequestering agents. The rinsing formula is pH-balanced and contains wetting and complexing agents. Emulsifiers in all the formulations help eliminate fugitive releases of volatile organic compounds or other vapors.

The chemical formulation in each stage is sprayed on the contaminated surface as a fine mist and worked into the surface with a stiff bristle brush or floor scrubber. The chemicals are allowed to penetrate into the subsurface and are then rinsed or vacuumed from the surface with a wet/dry, barrel-vacuum. No major capital equipment is required.

Contaminant levels can be reduced from 60 to 90 percent per cycle. The total number of cycles is determined from initial contaminant concentrations and final remedial action objectives.

**WASTE APPLICABILITY:**

The TechXtract® process is designed to treat porous solid materials contaminated with PCBs; toxic hydrocarbons; heavy metals, including lead and arsenic; and radionuclides. Because the contaminants are extracted from the surface, the materials can be left in place, reused, or recycled. After treatment, the contaminants are concentrated in a small volume of liquid waste. The liquid can be disposed as is, incinerated, or solidified for landfill. It will carry the waste characteristics of the contaminant.



Process Flow Diagram of the TECHXTRACT® Process

In commercial applications, the process has reduced PCB concentrations from 1,000,000 micrograms per 100 square centimeters ( $\mu\text{g}/100\text{ cm}^2$ ) to concentrations less than  $0.2\text{ }\mu\text{g}/100\text{ cm}^2$ . The TechXtract<sup>®</sup> process has been used on concrete floors, walls, and ceilings, tools and machine parts, internal piping, valves, and lead shielding. The TechExtract<sup>®</sup> process has removed lead, arsenic, technetium, uranium, cesium, tritium, and throrium, chrome (+3,+6), gallium, copper, mercury, plutonium, and strontium.

## STATUS:

This technology was accepted into the SITE Demonstration Program in summer 1994. EAT Demonstrated the TechXtract<sup>®</sup> technology from February 26, 1997 to March 6, 1997. During the demonstration, AET competed 20 TechXtract<sup>®</sup> 100 cycles and 12 300/200 cycles. Post-treatment samples were collected on March 6, 1997. In April 1997 a demonstration project was completed at the Pearl Harbor Naval Complex.

The technology has been used in over 200 successful decontamination projects for the U.S. Department of Energy; U.S. Department of Defense; the electric, heavy manufacturing, steel, and aluminum industries; and other applications. Further research is underway to apply the technology to soil, gravel, and other loose material. AET also plans to study methods for removing or concentrating metals in the extracted liquids.

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## ARIZONA STATE UNIVERSITY/ ZENTOX CORPORATION (Photocatalytic Oxidation with Air Stripping)

### TECHNOLOGY DESCRIPTION:

Chlorinated volatile organic compounds (VOC), such as trichloroethene (TCE) and tetrachloroethene (PCE), are readily removed from groundwater and soil using established methods such as air stripping and vapor extraction. However, this solution produces a VOC-contaminated air stream that requires further treatment.

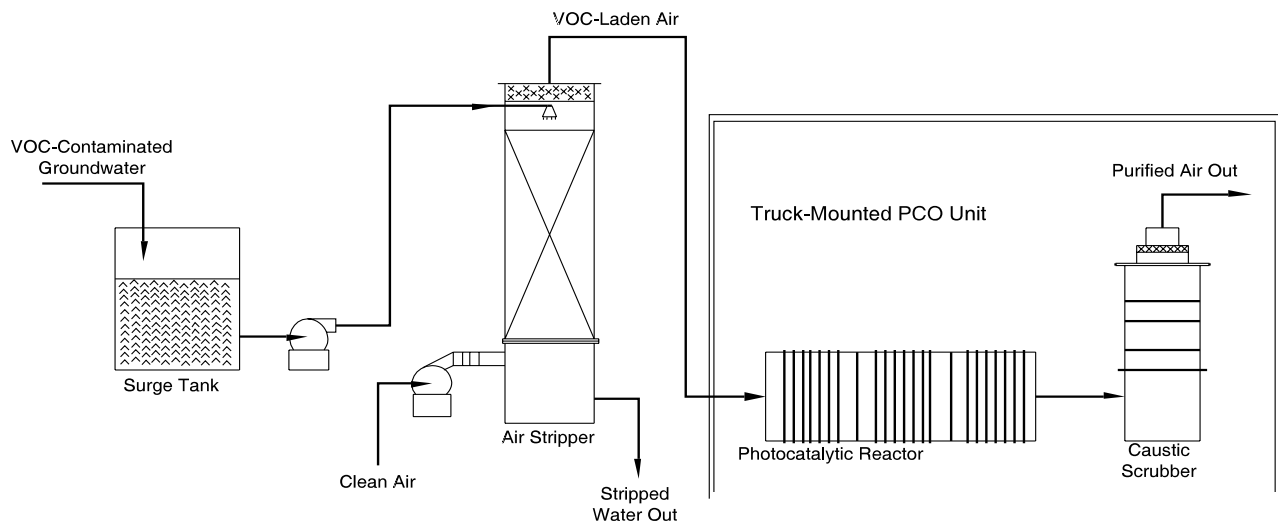
In gas-solid photocatalytic oxidation (PCO), the VOC-laden air stream is exposed to a titania catalyst in near-ultraviolet (UV) light. The UV light activates the catalyst, producing oxidizing radicals. The radicals promote rapid chain reactions that completely destroy VOCs to carbon dioxide and water; these oxidation reactions occur at or near room temperature. The treatment of chlorinated organics also produces hydrochloric acid.

Arizona State University (ASU) is investigating an integrated pilot-scale pump-and-treat system that transfers chlorinated VOCs to an air stream using air stripping. A PCO reactor installed downstream of the air stripping unit treats the contaminated air stream. The figure below illustrates the system. The PCO unit incorporates a flow-through photocatalytic reactor for VOC destruction and a caustic absorber bed for

removal of hydrochloric acid. The acid is neutralized to sodium chloride in the absorber bed.

PCO offers the following advantages over conventional treatment technologies:

- The photocatalytic process allows VOCs to be oxidized at or near room temperature.
- Low-temperature operation allows the use of plastic piping and construction, thereby reducing costs and minimizing acid corrosion problems.
- Chemical additives are not required.
- The titania catalyst and UV lamps are inexpensive and commercially available (modified catalyst formulations are available for enhanced performance).
- A variety of halogenated and nonhalogenated organic compounds can be completely oxidized to innocuous or easily neutralized products, such as carbon dioxide and hydrochloric acid.



Photocatalytic Oxidation with Air Stripping

## WASTE APPLICABILITY:

This technology can treat VOC-contaminated streams generated by air stripping treatment of contaminated groundwater or soil vapor extraction of contaminated soil. The technology is appropriate for dilute VOC concentrations (such as 500 parts per million by volume or less) and low to moderate flow rates. Laboratory data indicate that the PCO technology can also be adapted for industrial facilities that emit dilute VOC-contaminated air streams. Candidates include chemical process plants, dry cleaners, painting operations, solvent cleaning operations, and wastewater and hazardous waste treatment facilities. Air in closed environments could also be purified by integrating PCO units with heating, ventilation, and air conditioning systems.

## STATUS:

The PCO technology was accepted into the SITE Emerging Technology Program in 1993. Under the program, ASU has conducted bench-scale tests to evaluate the integration of a PCO unit downstream of an existing air stripping unit. Results of the bench-scale testing have provided design data for a pilot-scale test at a Phoenix, Arizona, Superfund site contaminated with chlorinated VOCs. ASU's previous laboratory studies indicate rapid destruction to nondetectable levels (98 to 99 percent removal) for various concentrations of TCE and other chlorinated ethenes in humid air streams.

In 1995, Zentox Corporation (Zentox) fielded a prototype PCO system for the treatment of TCE in air. Building on the data gained from that system, Zentox is fabricating a second generation system for use at the Phoenix site. Following tests at the Phoenix site, the 50- to 100-cubic-feet-per-minute pilot plant unit will be available for trials at other locations.

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**ART INTERNATIONAL, INC.**  
(formerly ENVIRO-SCIENCES, INC.)  
(Low-Energy Extraction Process)

**TECHNOLOGY DESCRIPTION:**

The patented Low-Energy Extraction Process (LEEP®) uses common organic solvents to concentrate and extract organic pollutants from soil, sediments, and sludges. LEEP® can treat contaminated solids to the stringent cleanup levels mandated by regulatory agencies. LEEP® includes pretreatment, washing, and concentration processes (see figure below).

During pretreatment, particles measuring up to 8 inches in diameter are removed in a gravity settler-floater. The settler-floater includes a metal detector and remover, a crusher, and a metering feeder. Floating material often found at remediation sites, such as wood chips, grass, or root material, is also removed.

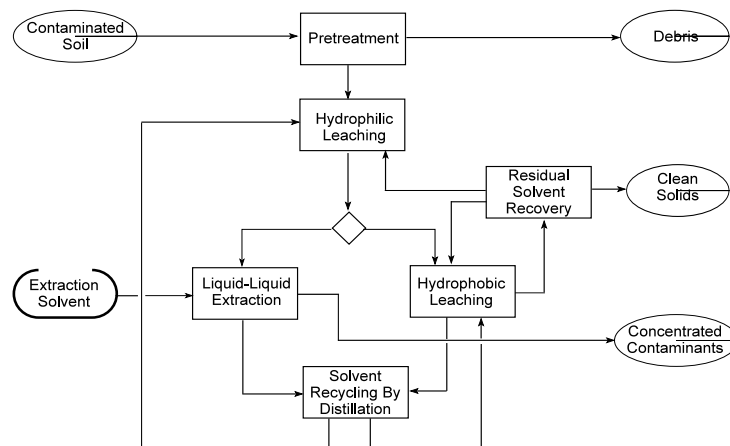
After pretreatment, the solid matrix is washed in a unique, dual solvent process that uses both hydrophilic and hydrophobic solvents. The combination of these proprietary solvents guarantees efficient contaminant removal.

The extracted pollutants are then concentrated in a sacrificial solvent by liquid-liquid extraction or by distillation, before being removed from the process for off-site disposal or recycling. The treated solids can be returned to the site as clean fill.

LEEP® is a low-pressure process operated at near-ambient conditions. It is designed as a closed-loop, self-contained, mobile unit consisting of proven heavy-duty equipment. The relatively inexpensive solvents used in the process are recycled internally. The solvents are applicable to almost every type of organic contaminant, and their physical properties enhance clay and silt particle settling.

**WASTE APPLICABILITY:**

LEEP® can treat most organic contaminants in soil, sediment, and sludge, including tar, creosote, chlorinated hydrocarbons, polynuclear aromatic hydrocarbons, pesticides, and wood- preserving chlorophenol formulations. Bench- and pilot-scale



LEEP® Process Flow Diagram

experiments have shown that LEEP® effectively treats tar-contaminated solids from manufactured gas plant sites, soils and sediments contaminated with polychlorinated biphenyls and refinery waste sludges, and soils contaminated with petroleum hydrocarbons.

## STATUS:

LEEP® was accepted into the Emerging Technology Program in July 1989. Bench-scale studies for process development were completed in 1994. A draft report that details the evaluation results has been submitted to EPA. The final report will be available in 1997.

In addition, ART International, Inc., routinely conducts bench-scale treatability studies for government and industrial clients, and it has obtained Toxic Substances Control Act, Resource Conservation and Recovery Act, and air permits for the technology. Other developments include the following:

- A 200-pound-per-hour pilot-scale unit has been constructed.
- Tests of the pilot-scale unit indicated that LEEP® can treat soil from manufactured gas plant sites containing up to 5 percent tar.
- Tests to scale up the pilot-scale unit to a commercial unit are complete.
- Commercial design criteria and a turnkey bid package are complete.
- Commercialization activities for a full-scale unit are underway.
- In 1994, Soil Extraction Technologies, Inc., a wholly owned subsidiary of Public Service Electric & Gas, purchased a LEEP® license.

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## ATOMIC ENERGY OF CANADA, LIMITED (Chemical Treatment and Ultrafiltration)

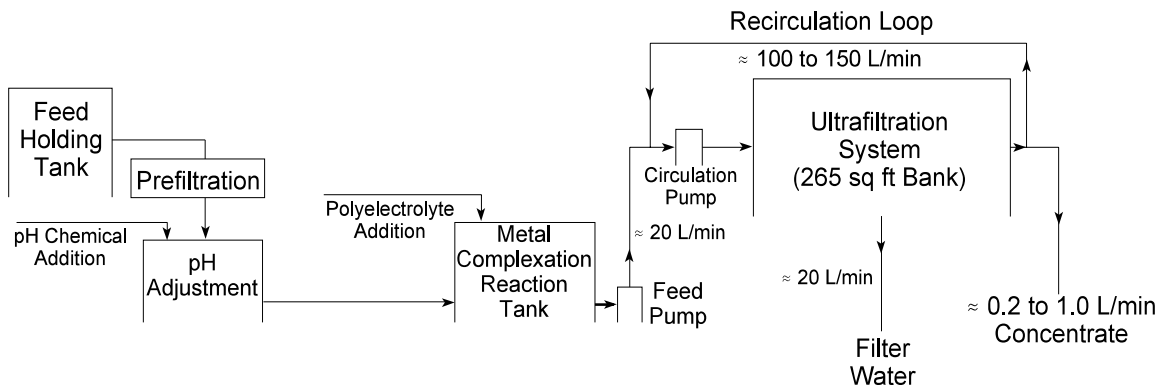
### TECHNOLOGY DESCRIPTION:

The Atomic Energy of Canada, Limited (AECL), process uses chemical pretreatment and ultrafiltration to remove trace concentrations of dissolved metals from wastewater, contaminated groundwater, and leachate. The process selectively removes metal contaminants and produces a volume-reduced water stream for further treatment and disposal.

The installed unit's overall dimensions are 5 feet wide by 7 feet long by 6 feet high. The skid-mounted unit consists of (1) a bank of 5-micron cartridge prefilters, (2) a feed conditioning system with polyelectrolytes and chemicals for pH adjustment, (3) two banks of hollow-fiber ultrafilters, (4) a backflush system for cleaning the membrane unit, and (5) associated tanks and instrumentation.

The figure below illustrates the process. Wastewater enters the prefilter through the feed holding tank, where suspended particles are removed from the feed. The filtered waste stream is then routed to conditioning tanks where the solution pH is adjusted. Water-soluble macromolecular compounds are then added to the wastewater to form complexes with heavy metal ions. Next, a relatively high molecular weight polymer, generally a commercially available polyelectrolyte, is added to the wastewater to form

selective metal-polymer complexes at the desired pH and temperature. The polyelectrolyte quantities depend on the metal ion concentration. The wastewater then passes through a cross-flow ultrafiltration membrane system by way of a recirculation loop. The ultrafiltration system provides a total membrane surface area of 265 square feet and a flow rate of about 6 gallons per minute (gpm). The membranes retain the metal complexes (concentrate), while allowing uncomplexed ions to pass through the membrane with the filtered water. The filtered water (permeate) is continuously withdrawn, while the concentrate stream, containing most of the contaminants, is recycled through the recirculation loop until it meets the target concentration. After reaching the target concentration, the concentrate stream is withdrawn for further treatment, such as solidification. It can then be safely disposed of, while the clean filtered water is discharged.



Single-Stage Chemical Treatment and Ultrafiltration Process

## WASTE APPLICABILITY:

The AECL process treats groundwater, leachate, and surface runoff contaminated with trace levels of toxic heavy metals. The process also treats effluents from (1) industrial processes, (2) production and processing of base metals, (3) smelters, (4) electrolysis operations, and (5) battery manufacturing. Potential applications include removal of metals such as cadmium, lead, mercury, uranium, manganese, nickel, chromium, and silver.

The process can treat influent with dissolved metal concentrations from several parts per million (ppm) up to about 100 ppm. In addition, the process removes other inorganic and organic materials present as suspended or colloidal solids. The sole residue is the ultrafiltration concentrate, which generally constitutes 5 to 20 percent of the feed volume.

## STATUS:

The AECL process was accepted into the SITE Emerging Technology Program in 1988. During initial bench-scale and pilot-scale tests, the AECL process successfully removed cadmium, lead, and mercury. These results were used to help designers construct the mobile unit.

The mobile unit has been tested at Chalk River Laboratories and a uranium mine tailings site in Ontario, Canada. The field evaluation indicated that process water characteristics needed further study; pretreatment schemes are being evaluated. The mobile unit, which is capable of treating influent flows ranging from 1,000 to 5,000 gallons per day, is available for treatability tests and on-site applications. An Emerging Technology Bulletin (EPA/540/F-92/002) is available from EPA.

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## ATOMIC ENERGY OF CANADA LIMITED (Ultrasonic-Aided Leachate Treatment)

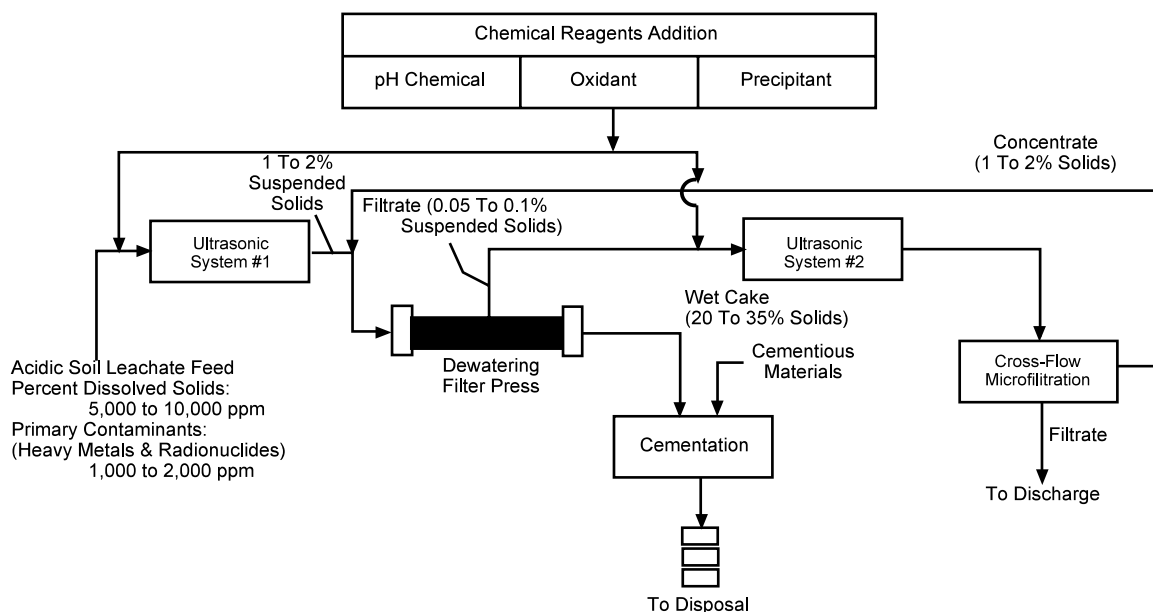
### TECHNOLOGY DESCRIPTION:

The ultrasonic-aided leachate treatment process involves enhanced chemical treatment of acidic soil leachate solutions. These solutions, also known as acid mine drainage, are caused by the oxidation and dissolution of sulfide-bearing wastes that produce sulfuric acid. The resulting acidic water leaches metal contaminants from the exposed waste rock and mine tailings, creating large volumes of toxic acidic leachates.

The ultrasonic-aided leachate treatment process uses an ultrasonic field to improve contaminant removal through precipitation, coprecipitation, oxidation, ion scavenging, and sorption (see figure below). These processes are followed by solid-liquid separation using a filter press and a cross-flow microfilter connected in series. The time required for treatment depends on (1) the nature of acidic waste to be treated, (2) the treated water quality with respect to contaminant concentration, and (3) the rate at which the physical and chemical processes occur. The treatable leachate volume is scalable.

conventional processes is the use of ultrasonic mixing instead of mechanical agitation in large tanks. Research indicates that an ultrasonic field significantly increases both the conversion rate of dissolved contaminants to precipitates and the rate of oxidation and ion exchange. Earlier studies by Atomic Energy of Canada Limited (AECL) revealed that the time required to precipitate heavy metals from aqueous solutions decreased by an order of magnitude in the presence of an ultrasonic field. The ultrasonic-aided leachate treatment process is compact, portable, and energy-efficient. Safety and process controls are built in as necessary for handling mixed radioactive solutions. The process also generates minimal fugitive emissions and produces a treated effluent that meets applicable discharge limits. The process may also be able to treat waste containing small amounts of dissolved or suspended organics.

The major difference between this technology and



Single-Stage Chemical Treatment and Ultrafiltration Process

## **WASTE APPLICABILITY:**

The ultrasonic-aided leachate treatment process treats acid mine drainage contaminated with heavy metals and radionuclides. The process can also be combined with soil remediation technologies.

## **STATUS:**

The ultrasonic-aided leachate treatment process was accepted into the SITE Emerging Technology Program in 1993. Under this program, AECL is developing and testing a pilot-scale unit to treat acidic soil leachate solutions containing low levels of metals and radionuclides.

The quality assurance and test plan was approved in October 1994. Laboratory-scale testing using acidic leachates from the Berkeley Pit in Butte, Montana, and from Stanleigh Mines in Elliot Lake, Ontario, Canada, is complete. The tests were designed to find optimal single and multistage treatment regimes to remove from the leachates a variety of dissolved species (such as iron, aluminum, manganese, magnesium, copper, zinc, uranium, radium, and sulfate), either as contaminants or as reusable resources.

Given optimum process chemistry, low energy (less than 5 kilojoules per liter), and low frequency (20 kilohertz), ultrasonic cavitation fields were sufficient to remove the dissolved species to levels meeting discharge requirements.

The energy input corresponds to a chemical conditioning time of a few seconds to tens of seconds. The underlying principles examined include lime and limestone precipitation, copper cementation, iron, and uranium oxidation, ion sorption, and ion scavenging.

A Phase 1 interim report summarizing the laboratory-scale results was issued in August 1995. A revised Phase 1 report was issued in February 1996. Testing of the pilot-scale system was December 1996.

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## BATTELLE MEMORIAL INSTITUTE (In Situ Electroacoustic Soil Decontamination)

### TECHNOLOGY DESCRIPTION:

This patented in situ electroacoustic soil decontamination (ESD) technology removes heavy metals from soils through direct current electrical and acoustic fields. Direct current facilitates liquid transport through soils. The technology consists of electrodes, an anode and a cathode, and an acoustic source (see figure below).

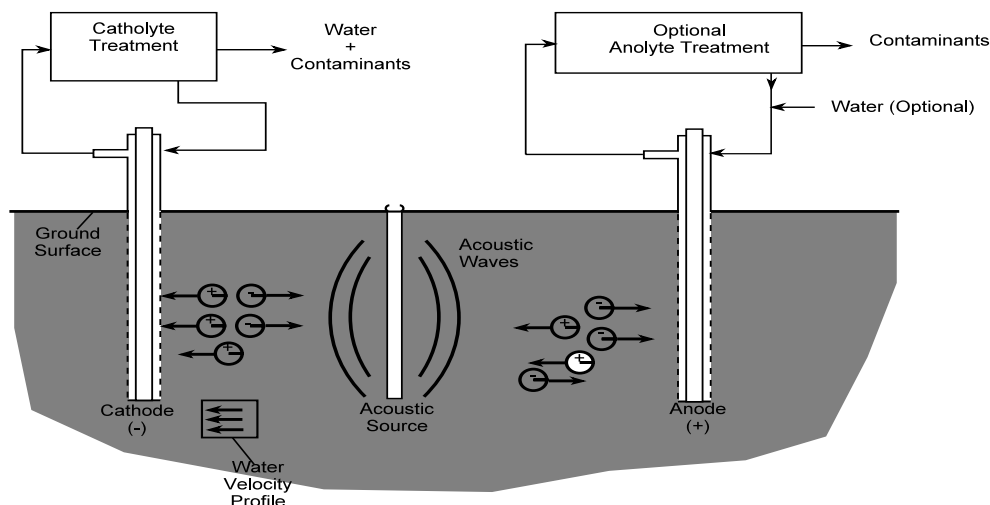
The double-layer boundary theory is important when an electric potential is applied to soils. For soil particles, the double layer consists of (1) a fixed layer of negative ions that are firmly held to the solid phase, and (2) a diffuse layer of more loosely held cations and anions. Applying an electric potential to the double layer displaces the loosely held ions to their respective electrodes. The cations take water with them as they move toward the cathode.

Besides water transport through wet soils, the direct current produces other effects, such as ion transfer, pH gradients development, electrolysis, oxidation and reduction, and heat generation.

Heavy metals present in contaminated soils can be leached or precipitated out of solution by electrolysis, oxidation and reduction reactions, or ionic migration. The soil contaminants may be (1) cations, such as cadmium, chromium, and lead; or (2) anions, such as cyanide, chromate, and dichromate. The existence of these ions in their respective oxidation states depends on soil pH and concentration gradients. Direct current is expected to increase the leaching rate and precipitate the heavy metals out of solution by establishing appropriate pH and osmotic gradients.

### WASTE APPLICABILITY:

This technology removes heavy metals from soils. When applied in conjunction with an electric field and water flow, an acoustic field can enhance waste dewatering or leaching. This phenomenon is not fully understood. Another possible application involves the unclogging of recovery wells. Because contaminated particles are driven to the recovery well, the pores and interstitial spaces in the soil can close. This technology could be used to clear these clogged spaces. The technology's potential for improving



In Situ Electroacoustic Soil Decontamination (ESD) Technology

nonaqueous phase liquid contaminant recovery and in situ removal of heavy metals needs to be tested at the pilot-scale level using clay soils.

### **STATUS:**

The ESD technology was accepted into the SITE Emerging Technology Program in 1988. Results indicate that ESD is technically feasible for removing inorganic species such as zinc and cadmium from clay soils; it is only marginally effective for hydrocarbon removal. A modified ESD process for more effective hydrocarbon removal has been developed but not tested. The Emerging Technology Report (EPA/540/5-90/004) describing the 1-year investigation can be purchased through the National Technical Information Service, (PB 90-204728/AS). The Emerging Technology Summary (EPA/540/S5-90/004) is available from EPA.

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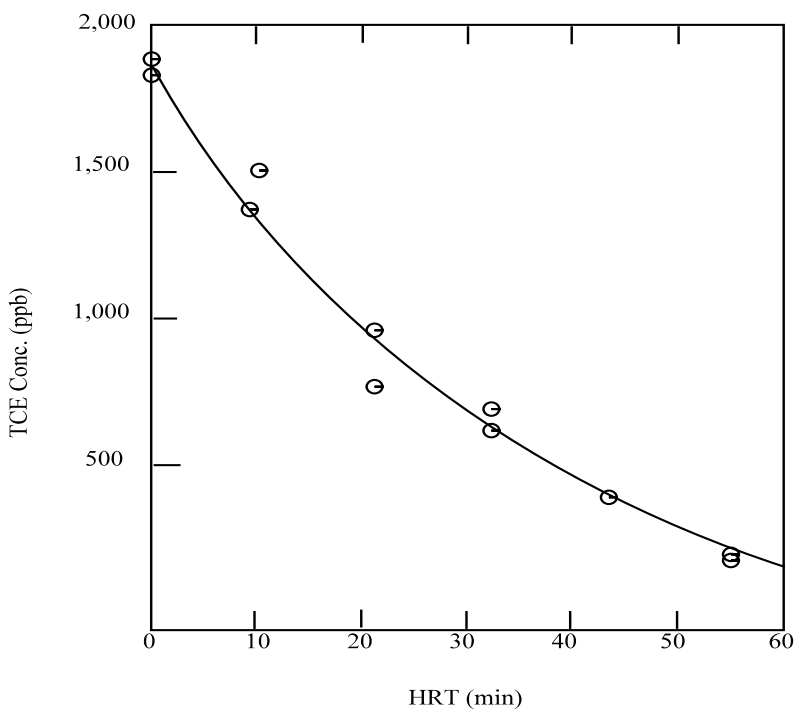
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## BIOTROL® (Methanotrophic Bioreactor System)

### TECHNOLOGY DESCRIPTION:

The BioTrol® methanotrophic bioreactor system is an aboveground remedial technology for water contaminated with halogenated hydrocarbons. Trichloroethene (TCE) and related compounds pose a difficult challenge to biological treatment. Unlike aromatic hydrocarbons, for example, TCE cannot serve as a primary substrate for bacterial growth. Degradation depends on cometabolism (see figure below), which is attributed to the broad substrate specificity of certain bacterial enzyme systems. Although many aerobic enzyme systems reportedly cooxidize TCE and related compounds, BioTrol® claims that the methane monooxygenase (MMO) produced by methanotrophic bacteria is the most promising.

Methanotrophs are bacteria that can use methane as a sole source of carbon and energy. Although certain methanotrophs can express MMO in either a soluble or particulate (membrane-bound) form, BioTrol® has discovered that the soluble form used in the BioTrol process induces extremely rapid TCE degradation rates. Two patents have been obtained, and an additional patent on the process is pending. Results from experiments with *Methylosinus trichosporium* strain OB3b indicate that the maximum specific TCE degradation rate is 1.3 grams of TCE per gram of cells (dry weight) per hour. This rate is 100 to 1,000 times faster than reported TCE degradation rates for nonmethanotrophs. This species of methanotrophic bacteria reportedly removes various chlorinated aliphatic compounds by more than 99.9 percent.



Results for Pilot-Scale, Continuous-Flow Reactor

BioTrol has also developed a colorimetric assay that verifies the presence of MMO in the bioreactor culture.

## **WASTE APPLICABILITY:**

The bioreactor system can treat water contaminated with halogenated aliphatic hydrocarbons, including TCE, dichloroethene isomers, vinyl chloride, dichloroethane isomers, chloroform, dichloromethane (methylene chloride), and others. In the case of groundwater treatment, bioreactor effluent can either be reinjected or discharged to a sanitary sewer or a National Pollutant Discharge Elimination System.

## **STATUS:**

This technology was accepted into the SITE Emerging Technology Program in July 1990. Both bench- and pilot-scale tests were conducted using a continuous-flow, dispersed-growth system. As shown in the figure below, the pilot-scale reactor displayed first-order TCE degradation kinetics. The final report on the demonstration appears in the *Journal of the Air and Waste Management Association*, Volume 45, No. 1, January 1995. The Emerging Technology Bulletin (EPA/540/F- 93/506) and the Emerging Technology Summary (EPA/540/SR-93/505) are available from EPA.

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**BWX TECHNOLOGIES, INC.**  
(an affiliate of **BABCOCK & WILCOX CO.**)  
(Cyclone Furnace)

**TECHNOLOGY DESCRIPTION:**

The Babcock & Wilcox Co. (Babcock & Wilcox) cyclone furnace is designed to combust coal with high inorganic content (high-ash). Through cofiring, the cyclone furnace can also accommodate highly contaminated wastes containing heavy metals and organics in soil or sludge. High heat-release rates of 45,000 British thermal units (Btu) per cubic foot of coal and high turbulence in cyclones ensures the high temperatures required for melting the high-ash fuels and combusting the organics. The inert ash exits the cyclone furnace as a vitrified slag.

The pilot-scale cyclone furnace, shown in the figure below, is a water cooled, scaled-down version of a commercial coal-fired cyclone with a restricted exit (throat). The furnace geometry is a horizontal cylinder (barrel).

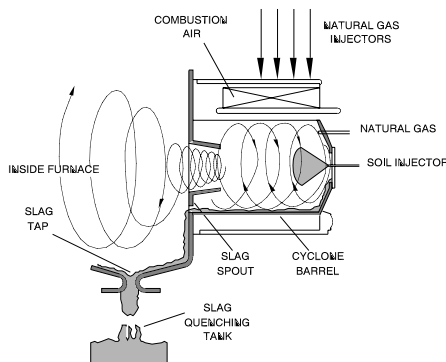
Natural gas and preheated combustion air are heated to 820 °F and enter tangentially into the cyclone burner. For dry soil processing, the soil matrix and natural gas enter tangentially along the cyclone furnace barrel. For wet soil processing, an atomizer uses compressed air to spray the soil slurry directly into the furnace.

The soil or sludge and inorganics are captured and melted, and organics are destroyed in the gas phase or in the molten slag layer. This slag layer is formed and retained on the furnace barrel wall by centrifugal action.

The soil melts, exits the cyclone furnace from the tap at the cyclone throat, and drops into a water-filled slag tank where it solidifies. A small quantity of soil also exits as fly ash with the flue gas from the furnace and is collected in a baghouse. In principle, this fly ash can be recycled to the furnace to increase metal capture and to minimize the volume of the potentially hazardous waste stream.

The energy requirements for vitrification are 15,000 Btu per pound of soil treated. The cyclone furnace can be operated with gas, oil, or coal as the supplemental fuel. If the waste is high in organic content, it may also supply a significant portion of the required fuel heat input.

Particulates are captured by a baghouse. To maximize the capture of particulate metals, a heat exchanger is used to cool the stack gases to approximately 200°F before they enter the baghouse.



**Cyclone Furnace**

## **WASTE APPLICABILITY:**

The cyclone furnace can treat highly contaminated hazardous wastes, sludges, and soils that contain heavy metals and organic constituents. The wastes may be solid, a soil slurry (wet soil), or liquids. To be treated in the cyclone furnace, the ash or solid matrix must melt (with or without additives) and flow at cyclone furnace temperatures (2,400 to 3,000°F). Because the furnace captures heavy metals in the slag and renders them nonleachable, it is particularly suited to soils that contain lower-volatility radionuclides such as strontium and transuranics.

## **STATUS:**

Based on results from the Emerging Technology Program, the cyclone furnace technology was accepted into the SITE Demonstration Program in August 1991. A demonstration occurred in November 1991 at the developer's facility in Alliance, Ohio. The process was demonstrated using an EPA-supplied, wet synthetic soil matrix (SSM) spiked with heavy metals (lead, cadmium, and chromium), organics (anthracene and dimethylphthalate), and simulated radionuclides (bismuth, strontium, and zirconium). Results from the demonstrations have been published in the Applications Analysis Report (EPA/520/AR-92/017) and Technology Evaluation Report, Volumes 1 and 2 (EPA/504/R-92/017A and EPA/540/R-92/017B); these documents are available from EPA.

## **DEMONSTRATION RESULTS:**

Vitrified slag leachabilities for the heavy metals met EPA toxicity characteristic leaching procedure (TCLP) limits. TCLP leachabilities were 0.29 milligram per liter (mg/L) for lead, 0.12 mg/L for cadmium, and 0.30 mg/L for chromium. Almost 95 percent of the noncombustible SSM was incorporated into the slag. Greater than 75 percent of the chromium, 88 percent of the strontium, and 97 percent of the zirconium were

captured in the slag. Dry weight volume was reduced 28 percent. Destruction and removal efficiencies for anthracene and dimethylphthalate were greater than 99.997 percent and 99.998 percent, respectively. Stack particulates were 0.001 grain per dry standard cubic foot (gr/dscf) at 7 percent oxygen, which was below the Resource Conservation Recovery Act limit of 0.08 gr/dscf effective until May 1993. Carbon monoxide and total hydrocarbons in the flue gas were 6.0 parts per million (ppm) and 8.3 ppm, respectively.

An independent cost analysis was performed as part of the SITE demonstration. The cost to remediate 20,000 tons of contaminated soil using a 3.3-ton-per-hour unit was estimated at \$465 per ton if the unit is on line 80 percent of the time, and \$529 per ton if the unit is on line 60 percent of the time.

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## COGNIS, INC. (Biological/Chemical Treatment)

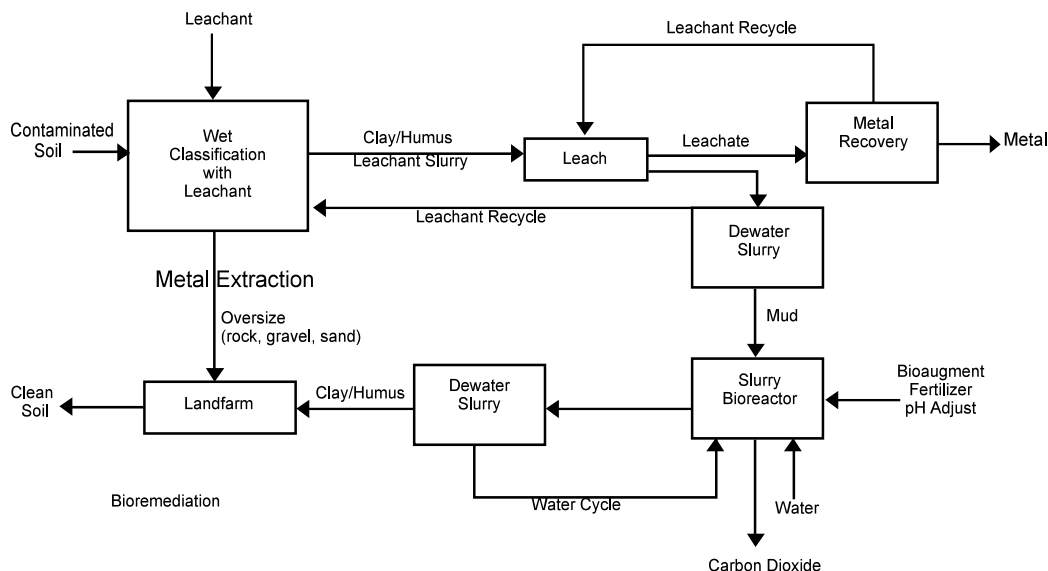
### TECHNOLOGY DESCRIPTION:

The COGNIS, Inc. biological/chemical treatment is a two-stage process that treats soils, sediments, and other media contaminated with metals and organics. Metals are first removed from the contaminated matrix by a chemical leaching process. Organics are then removed by bioremediation.

Although metals removal usually occurs in the first stage, bioremediation may be performed first if organic contamination levels are found to inhibit the metals extraction process. Bioremediation is more effective if the metal concentrations in the soil are sufficiently low so as not to inhibit microbial activity. However, even in the presence of inhibitory metal concentrations, a microbe population may be enriched to perform the necessary bioremediation.

Soil handling requirements for both stages are similar, so unit operations are fully reversible. The final treatment products are a recovered metal or metal salt, biodegraded organic compounds, and clean soil. Contaminated soil is first exposed to a leachant solution and classified by particle size (see figure below). Size classification allows oversized rock, gravel, and sand to be quickly cleaned and separated from the sediment fines (such as silt, clay, and humus), which require longer leaching times. Typically, organic pollutants are also attached to the fines.

After dissolution of the metal compounds, metal ions such as zinc, lead, and cadmium are removed from the aqueous leachate by liquid ion exchange, resin ion exchange, or reduction. At this point, the aqueous leaching solution is freed of metals and can be reused to leach additional metal from the contaminated soil. If an extraction agent is used, it is later stripped of the



Metal Leaching and Bioremediation Process

bound metal and the agent is fully regenerated and recycled. Heavy metals are recovered in a saleable, concentrated form as solid metal or a metal salt. The method of metals recovery depends on the metals present and their concentrations.

After metals extraction is complete, the "mud" slurry settles and is neutralized. Liquids are returned to the classifier, and the partially treated soil is transferred to a slurry bioreactor, a slurry-phase treatment lagoon, or a closed land treatment cell for bioremediation. The soil and the residual leachate solution are treated to maximize contaminant biodegradation. Nutrients are added to support microbial growth, and the most readily biodegradable organic compounds are aerobically degraded.

Bench-scale tests indicate that this process can remediate a variety of heavy metals and organic pollutants. The combined process is less expensive than separate metals removal and organic remediation.

### **WASTE APPLICABILITY:**

This remediation process is intended to treat combined-waste soils contaminated by heavy metals and organic compounds. The process can treat contaminants including lead, cadmium, zinc, and copper, as well as petroleum hydrocarbons and polynuclear aromatic hydrocarbons that are subject to aerobic microbial degradation. The combined process can also be modified to extract mercury and other metals, and to degrade more recalcitrant halogenated hydrocarbons.

### **STATUS:**

This remediation process was accepted into the SITE Emerging Technology Program in August 1992. Bench- and pilot-scale testing of the bioremediation process is complete. A full-scale field test of the metals extraction process was completed under the Demonstration Program. For further information on the full-scale process, refer to the profile in the Demonstration Program section.

This remediation process is no longer available through COGNIS, Inc. For further information about the process, contact the EPA Project Manager.

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**COGNIS, INC.**  
**(TERRAMET® Soil Remediation System)**

**TECHNOLOGY DESCRIPTION:**

The COGNIS, Inc. (COGNIS), TERRAMET® soil remediation system leaches and recovers lead and other metals from contaminated soil, dust, sludge, or sediment. The system uses a patented aqueous leachant that is optimized through treatability tests for the soil and the target contaminant. The TERRAMET® system can treat most types of lead contamination, including metallic lead and lead salts and oxides. The lead compounds are often tightly bound by fine soil constituents such as clay, manganese and iron oxides, and humus.

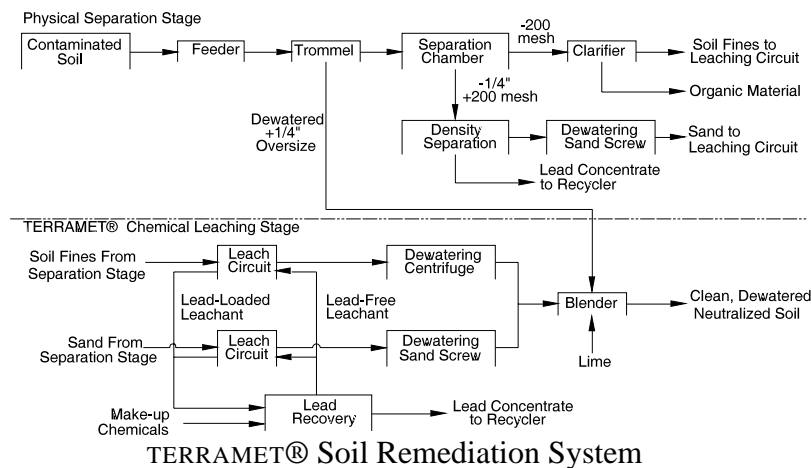
The figure below illustrates the process. A pretreatment, physical separation stage may involve dry screening to remove gross oversized material. The soil can be separated into oversized (gravel), sand, and fine (silt, clay, and humus) fractions. Soil, including the oversized fraction, is first washed. Most lead contamination is typically associated with fines fraction, and this fraction is subjected to countercurrent leaching to dissolve the adsorbed lead and other heavy metal species. The sand fraction may also contain significant lead, especially if the contamination is due to particulate lead, such as that found in battery recycling, ammunition burning, and

scrap yard activities. In this case, the sand fraction is pretreated to remove dense metallic or magnetic materials before subjecting the sand fraction to countercurrent leaching. Sand and fines can be treated in separate parallel streams.

After dissolution of the lead and other heavy metal contaminants, the metal ions are recovered from the aqueous leachate by a metal recovery process such as reduction, liquid ion exchange, resin ion exchange, or precipitation. The metal recovery technique depends on the metals to be recovered and the leachant employed. In most cases, a patented reduction process is used so that the metals are recovered in a compact form suitable for recycling. After the metals are recovered, the leachant can be reused within the TERRAMET® system for continued leaching.

Important characteristics of the TERRAMET® leaching/recovery combination are as follows:

- (1) the leachant is tailored to the substrate and the contaminant;
- (2) the leachant is fully recycled within the treatment plant;
- (3) treated soil can be returned on site;
- (4) all soil fractions can be treated;
- (5) end products include treated soil and recycled metal;
- and (6) no waste is generated during processing.



## WASTE APPLICABILITY:

The COGNIS TERRAMET® soil remediation system can treat soil, sediment, and sludge contaminated by lead and other heavy metals or metal mixtures. Appropriate sites include contaminated ammunition testing areas, firing ranges, battery recycling centers, scrap yards, metal plating shops, and chemical manufacturers. Certain lead compounds, such as lead sulfide, are not amenable to treatment because of their exceedingly low solubilities. The system can be modified to leach and recover other metals, such as cadmium, zinc, copper, and mercury, from soils.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in August 1992. Based on results from the Emerging Technology Program, the technology was accepted into the SITE Demonstration Program in 1994. The demonstration took place at the Twin Cities Army Ammunition Plant (TCAAP) Site F during August 1994. The TERRAMET® system was evaluated during a full-scale remediation conducted by COGNIS at TCAAP. The full-scale system was linked with a soil washing process developed by Brice Environmental Services Corporation (BESCOP). The system treated soil at a rate of 12 to 15 tons per hour. An Innovative Technology Evaluation Report describing the demonstration and its results will be available in 1998.

The TERRAMET® system is now available through Doe Run, Inc. (see contact information below). For further information about the development of the system, contact the Dr. William Fristad (see contact information below). For further information on the BESCOP soil washing process, refer to the profile in the Demonstration Program section (completed projects).

## DEMONSTRATION RESULTS:

Lead levels in the feed soil ranged from 380 to 1,800 milligrams per kilogram (mg/kg). Lead levels in untreated and treated fines ranged from 210 to 780 mg/kg and from 50 to 190 mg/kg, respectively. Average removal efficiencies for lead were about 75 percent. The TERRAMET® and BESCOP processes operated smoothly at a feed rate of 12 to 15 tons per hour. Size separation using the BESCOP process proved to be effective and reduced the lead load to the TERRAMET® leaching process by 39 to 63 percent. Leaching solution was recycled, and lead concentrates were delivered to a lead smelting facility. The cost of treating contaminated soil at the TCAAP site using the COGNIS and BESCOP processes is about \$200 per ton of treated soil, based on treatment of 10,000 tons of soil. This cost includes the cost of removing ordnance from the soil.

## FOR FURTHER INFORMATION:

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## COLORADO DEPARTMENT OF PUBLIC HEALTH AND ENVIRONMENT (Constructed Wetlands-Based Treatment)

### TECHNOLOGY DESCRIPTION:

The constructed wetlands-based treatment technology uses natural geochemical and microbiological processes inherent in an artificial wetland ecosystem to accumulate and remove metals from influent waters. The treatment system incorporates principal ecosystem components found in wetlands, such as organic materials (substrate), microbial fauna, and algae.

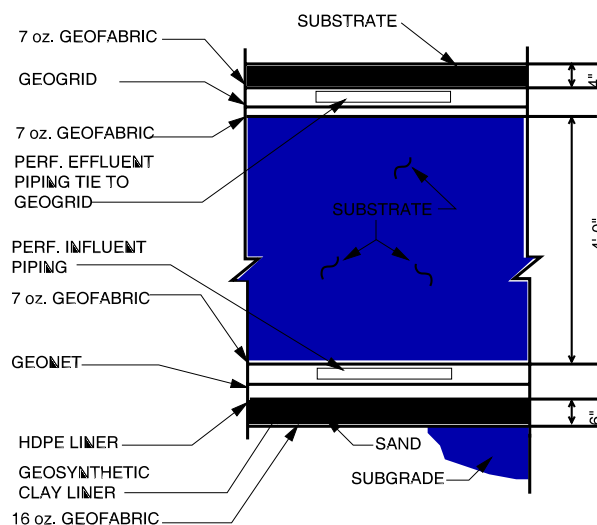
Influent waters with high metal concentrations flow through the aerobic and anaerobic zones of the wetland ecosystem. Metals are removed by ion exchange, adsorption, absorption, and precipitation through geochemical and microbial oxidation and reduction. Ion exchange occurs as metals in the water contact humic or other organic substances in the soil medium. Oxidation and reduction reactions that occur in the aerobic and anaerobic zones, respectively, precipitate metals as hydroxides and sulfides. Precipitated and adsorbed metals settle in quiescent ponds or are filtered out as the water percolates through the soil or substrate.

### WASTE APPLICABILITY:

The constructed wetlands-based treatment process is suitable for acid mine drainage from metal or coal mining activities. These wastes typically contain high concentrations of metals and low pH. Wetlands treatment has been applied with some success to wastewater in the eastern United States. The process may have to be adjusted to account for differences in geology, terrain, trace metal composition, and climate in the metal mining regions of the western United States.

### STATUS:

Based on the results of tests conducted during the SITE Emerging Technology Program (ETP), the constructed wetlands-based treatment process was selected for the SITE Demonstration Program in 1991. Results from the ETP tests indicated an average removal rate of 50 percent for metals. For further information on the ETP evaluation, refer to the Emerging Technology Summary (EPA/540/SR-



Schematic Cross Section of Pilot-Scale Upflow Cell

93/523), the Emerging Technology Report (EPA/540/R-93/523), or the Emerging Technology Bulletin (EPA/540/F-92/001), which are available from EPA.

This technology was in operation from 1993 to May 1999. It has been discontinued.

## **DEMONSTRATION RESULTS:**

Studies under the Demonstration Program evaluated process effectiveness, toxicity reduction, and biogeochemical processes at the Burleigh Tunnel, near Silver Plume, Colorado. Treatment of mine discharge from the Burleigh Tunnel is part of the remedy for the Clear Creek/Central City Superfund site. Construction of a pilot-scale treatment system began in summer 1993 and was completed in November 1993. The pilot-scale treatment system covered about 4,200 square feet and consisted of an upflow cell (see figure on previous page) and a downflow cell. Each cell treats about 7 gallons per minute of flow. Preliminary results indicated high removal efficiency (between 80 to 90 percent) for zinc, the primary contaminant in the discharge during summer operation. Zinc removal during the first winter of operation ranged from 60 to 80 percent.

Removal efficiency of dissolved zinc for the upflow cell between March and September remained above 90 percent; however, the removal efficiency between September and December 1994 declined to 84 percent due to the reduction in microbial activity in the winter months. The removal efficiency in the downflow cell dropped to 68 percent in the winter months and was between 70 and 80 percent during the summer months. The 1995 removal efficiency of dissolved zinc for the upflow cell declined from 84 percent to below 50 percent due to substrate hydrologic problems originating from attempts to insulate this unit during the summer months. A dramatic upset event in the spring of 1995 sent about four times the design flow through the upflow cell, along with a heavy zinc load. The heavy zinc load was toxic to the upflow cell and it never recovered to previous performance levels. Since the upset event, removal efficiency remained at or near 50 percent.

The 1995 removal efficiency of the downflow cell declined from 80 percent during the summer months to 63 percent during winter, again a result of reduced microbial activity. The 1996 removal efficiency of dissolved zinc calculated for the downflow cell increased from a January low of 63 percent to over 95 percent from May through August. The increase in the downflow removal efficiency is related to reduced flow rates through the downflow substrate, translating to increased residence time.

The SITE demonstration was completed in mid-1998, and the cells were decommissioned in August 1998. An Innovative Technology Evaluation Report for the demonstration will be available in 1999. Information on the technology can be obtained through below-listed sources.

## **FOR FURTHER INFORMATION:**

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## CONCURRENT TECHNOLOGIES

(formerly Center for Hazardous Materials Research)  
(Acid Extraction Treatment System)

### TECHNOLOGY DESCRIPTION:

The acid extraction treatment system (AETS) uses hydrochloric acid to extract heavy metal contaminants from soils. Following treatment, the clean soil may be returned to the site or used as fill.

A simplified block flow diagram of the AETS is shown below. First, soils are screened to remove coarse solids. These solids, typically greater than 4 millimeters in size, are relatively clean and require at most a simple rinse with water or detergent to remove smaller attached particles.

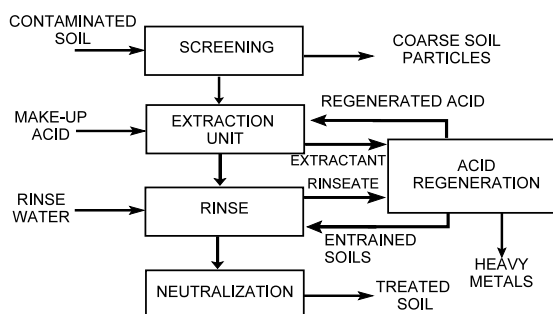
After coarse particle removal, the remaining soil is scrubbed in an attrition scrubber to break up agglomerates and cleanse surfaces. Hydrochloric acid is then introduced into the soil in the extraction unit. The residence time in the unit varies depending on the soil type, contaminants, and contaminant concentrations, but generally ranges between 10 and 40 minutes. The soil-extractant mixture is continuously pumped out of the mixing tank, and the soil and extractant are separated using hydrocyclones.

When extraction is complete, the solids are transferred to the rinse system. The soils are rinsed with water to remove entrained acid and metals. The extraction solution and rinse waters are regenerated using a proprietary technology that removes the metals and reforms the acid. The heavy metals are concentrated in a form potentially suitable for recovery. During the final step, the soils are mixed with lime and fertilizer to neutralize any residual acid. No wastewater streams are generated by the process.

### WASTE APPLICABILITY:

The main application of AETS is extraction of heavy metals from soils. The system has been tested using a variety of soils containing one or more of the following: arsenic, cadmium, chromium, copper, lead, nickel, and zinc. The treatment capacity is expected to range up to 30 tons per hour. AETS can treat all soil fractions, including fines.

The major residuals from AETS treatment include the cleaned soil, which is suitable for fill or for return to the site, and the heavy metal concentrate. Depending on the concentration of heavy metals, the mixtures of heavy metals found at the site, and the presence of other compounds (calcium, sodium) with the metals, heavy metals may be reclaimed from the concentrate.



Acid Extraction Treatment System (AETS) Process

## STATUS:

Under the Emerging Technology Program, laboratory-scale and bench-scale tests were conducted to develop the AETS technology. The bench-scale pilot system was constructed to process between 20 and 100 kilograms of soil per hour. Five soils were tested, including an EPA synthetic soil matrix (SSM) and soils from four Superfund sites, including NL Industries in Pedricktown, New Jersey; King of Prussia site in Winslow Township, New Jersey; a smelter site in Butte, Montana; and Palmerton Zinc site in Palmerton, Pennsylvania. These soils contained elevated concentrations of some or all of the following: arsenic, cadmium, chromium, copper, lead, nickel, and zinc. The table below summarizes soil treatability results based on the EPA Resource Conservation and Recovery Act (RCRA) hazardous waste requirements for toxicity characteristic leaching procedure (TCLP) and the California standards for total metal concentrations. The Emerging Technology Report (EPA/540/R-94/513) and Emerging Technology Summary (EPA/540/SR-94/513) are available from EPA.

The results of the study are summarized below:

- AETS can treat a wide range of soils containing a wide range of heavy metals to reduce the TCLP below the RCRA limit. AETS can also reduce the total metals concentrations below the California-mandated total metals limitations.
- In most cases, AETS can treat the entire soil, without separate stabilization and disposal for fines or clay particles, to the required TCLP and total metal limits. The only exception was the SSM, which may require separate stabilization and disposal of 20 percent of the soil to reduce the total TCLP lead concentrations appropriately. However, AETS successfully treated arsenic, cadmium, chromium, copper, nickel, and zinc in the soil.

- Treatment costs under expected process conditions range from \$100 to \$180 per cubic yard of soil, depending on the site size, soil types, and contaminant concentrations. Operating costs ranged from \$50 to \$80 per cubic yard.

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## CONCURRENT TECHNOLOGIES

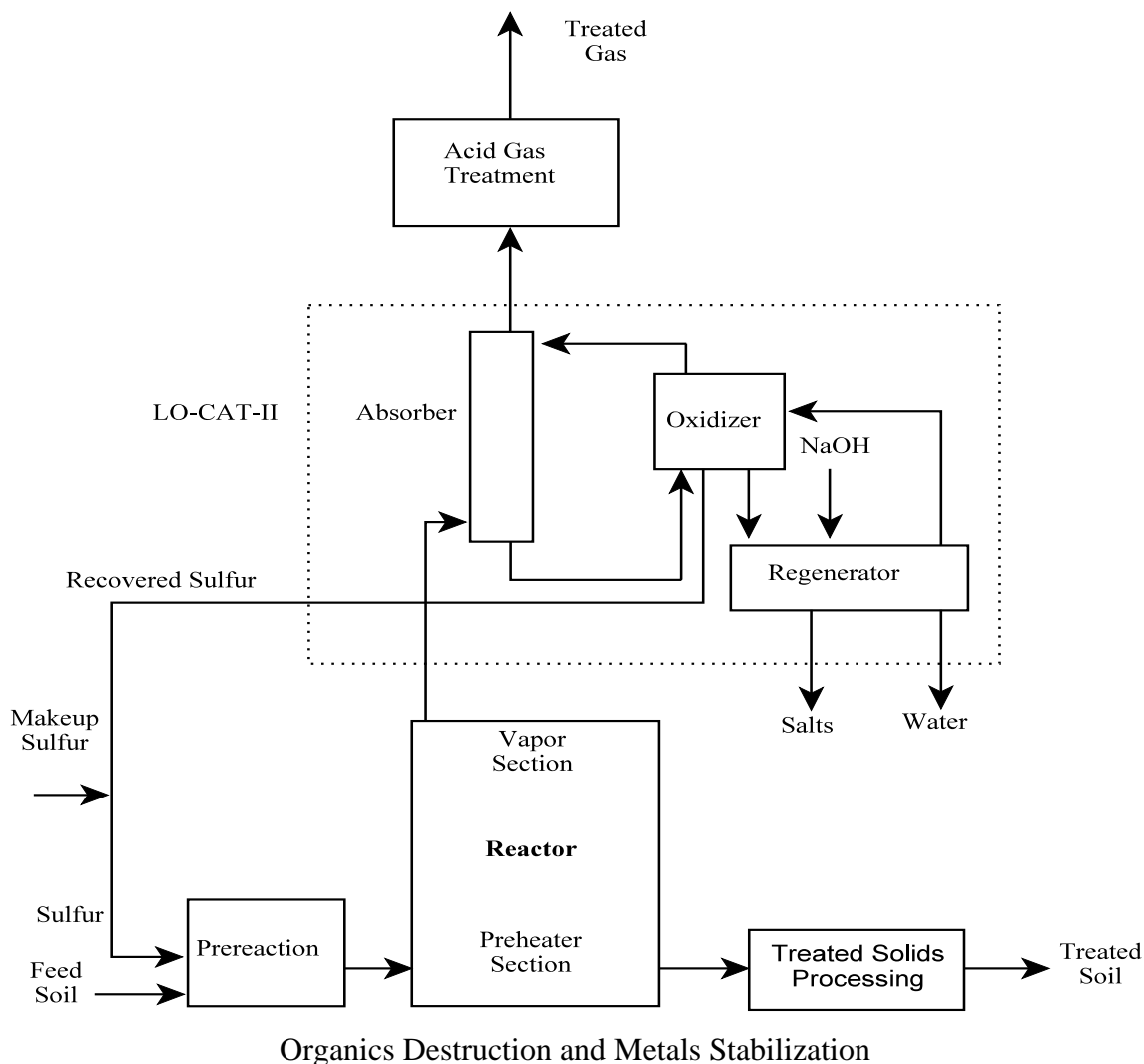
(formerly Center for Hazardous Materials Research)  
(Organics Destruction and Metals Stabilization)

### TECHNOLOGY DESCRIPTION:

This technology is designed to destroy hazardous organics in soils while simultaneously stabilizing metals and metal ions (see figure below). The technology causes contaminated liquids, soils, and sludges to react with elemental sulfur at elevated temperatures. All organic compounds react with sulfur. Hydrocarbons are converted to an inert carbon-sulfur powdered residue and hydrogen sulfide gas; treated chlorinated hydrocarbons also produce

hydrochloric acid gas. These acid gases are recovered from the off-gases. The hydrogen sulfide is oxidized in a conventional acid gas treating unit (such as ARI Technologies LO-CAT™), recovering the sulfur for reuse.

In addition to destroying organic compounds, the technology converts heavy metals to sulfides, which are rendered less leachable. If required, the sulfides can be further stabilized before disposal. Thus, heavy metals can be stabilized in the same process step as the organics destruction. The technology's main process



components consist of the following:

- A prereaction mixer where the solid and reagent are mixed
- An indirectly heated, enclosed reactor that includes a preheater section to drive off water, and two integrated reactor sections to react liquid sulfur with the solids and further react desorbed organic compounds with vapor-phase sulfur
- An acid gas treatment system that removes the acid gases and recovers sulfur by oxidizing the hydrogen sulfide
- A treated solids processing unit that recovers excess reagent and prepares the treated product to comply with on-site disposal requirements

Initial pilot-scale testing of the technology has demonstrated that organic contaminants can be destroyed in the vapor phase with elemental sulfur. Tetrachloroethene, trichloroethene, and polychlorinated biphenyls were among the organic compounds destroyed.

Batch treatability tests of contaminated soil mixtures have demonstrated organics destruction and immobilization of various heavy metals. Immobilization of heavy metals is determined by the concentration of the metals in leachate compared to EPA toxicity characteristic leaching procedure (TCLP) regulatory limits. Following treatment, cadmium, copper, lead, nickel, and zinc were significantly reduced compared to TCLP values. In treatability tests with approximately 700 parts per million of Aroclor 1260, destruction levels of 99.0 to 99.95 percent were achieved. Destruction of a pesticide, malathion, was also demonstrated. The process was also demonstrated to be effective on soil from manufactured gas plants, containing a wide range of polynuclear aromatics.

The current tests are providing a more detailed definition of the process limits, metal concentrations, and soil types required for stabilization of various heavy metals to meet the limits specified by TCLP. In addition, several process enhancements are being evaluated to expand the range of applicability.

### **WASTE APPLICABILITY:**

The technology is applicable to soils and sediments contaminated with both organics and heavy metals.

### **STATUS:**

This technology was accepted into the SITE Emerging Technology Program in January 1993. Bench-scale testing in batch reactors was completed in 1993. The pilot-scale program was directed at integrating the process concepts and obtaining process data in a continuous unit. The program was completed in 1995 and the Emerging Technology Report was made available in 1997.

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## CONCURRENT TECHNOLOGIES (formerly Center for Hazardous Materials Research) (Smelting Lead-Containing Waste)

### TECHNOLOGY DESCRIPTION:

Secondary lead smelting is a proven technology that reclaims lead from lead-acid battery waste sites. The Concurrent Technologies and Exide Corporation (Exide) have demonstrated the use of secondary lead smelting to reclaim usable lead from various types of waste materials from Superfund and other lead-containing sites. Reclamation of lead is based on existing lead smelting procedures and basic pyrometallurgy.

The figure below is a generalized process flow diagram. Waste material is first excavated from Superfund sites or collected from other sources. The waste is then preprocessed to reduce particle size and to remove rocks, soil, and other debris. Next, the waste is transported to the smelter.

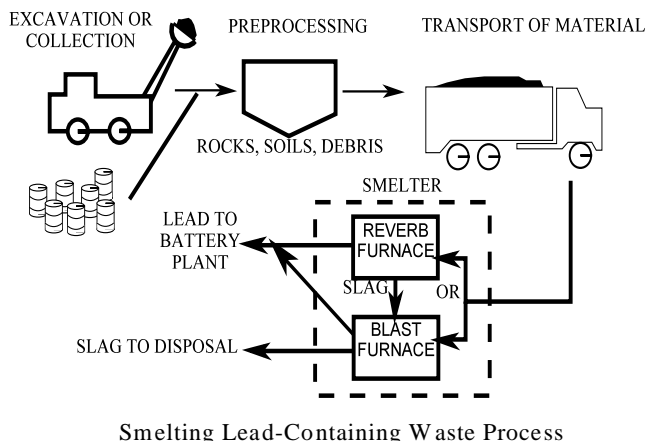
At the smelter, waste is fed to reverberatory or blast furnaces, depending on particle size or lead content. The two reverberatory furnaces normally treat lead from waste lead-acid batteries, as well as other lead-containing material. The furnaces are periodically tapped to remove slag, which contains 60 to 70 percent lead, and a soft pure lead product.

The two blast furnaces treat slag generated from the reverberatory furnaces, as well as larger- sized lead-containing waste. These furnaces are tapped continuously for lead and tapped intermittently to remove slag, which is

transported offsite for disposal. The reverberatory and blast furnace combination at Exide can reclaim lead from batteries and waste with greater than 99 percent efficiency.

### WASTE APPLICABILITY:

The process has been demonstrated to reclaim lead from a variety of solid materials, including rubber battery case material, lead dross, iron shot abrasive blasting material, and wood from demolition of houses coated with lead paint. The technology is applicable to solid wastes containing more than 2 percent lead, provided that they do not contain excessive amounts of calcium, silica, aluminum, or other similar constituents. Explosive and flammable liquids cannot be processed in the furnace. As tested, this technology is not applicable to soil remediation.



Smelting Lead-Containing Waste Process

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in July 1991. Field work for the project was completed in February 1993.

The process was tested at three Superfund sites. Materials obtained from two additional sites were also used for these tests. Results from the Emerging Technology Program, presented in the table below, show that the process is applicable to waste materials at each site and economically feasible for all but demolition material. The Emerging Technology Bulletin (EPA/540/F-94/510), the Emerging Technology Summary (EPA/540/SR-95/504), and the Emerging Technology Report (EPA/540/R-95/504) are available from EPA. An article about the technology was also published by the *Journal of Hazardous Materials* in February 1995.

Specific technical problems encountered included (1) loss of furnace production due to material buildup within the furnaces, (2) breakdowns in the feed system due to mechanical overloads, and (3) increased oxygen demands inside the furnaces. All of these problems were solved by adjusting material feed rates or furnace parameters. Based on these tests, Concurrent Technologies has concluded that secondary lead smelting is an economical method of reclaiming lead from lead-containing waste material collected at Superfund sites and other sources.

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Source of Material/ Type of Material Tested	% Lead	Economical *	Test Results
Tonolli Superfund site (PA)/ Battery cases	3 to 7	Yes	Lead can be reclaimed in secondary lead smelter; incorporated into regular blast furnace feed stock.
Hebalka Superfund site (PA)/ Battery cases	10	Yes	Lead can be reclaimed in secondary lead smelter; reduced in size and incorporated into regular reverberatory furnace feed stock.
Pedricktown Superfund site (NJ)/ Battery cases; lead dross, residue, and debris	45	Yes	Lead can be reclaimed in secondary lead smelter; screened and incorporated into regular reverberatory and blast furnace feed stocks.

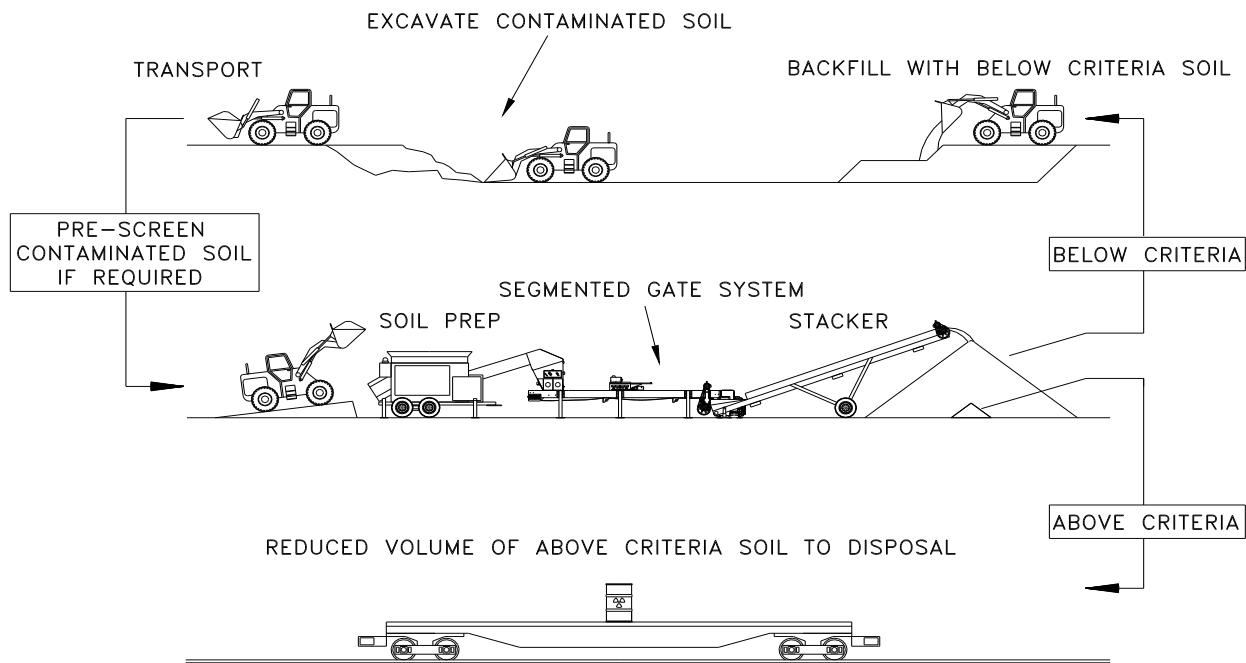
## Results from Field Tests of the Smelting Lead-Containing Waste Technology

**EBERLINE SERVICES, INC.**  
(formerly Thermo Nutech, Inc./TMA Thermo Analytical, Inc.)  
(Segmented Gate System)

**TECHNOLOGY DESCRIPTION:**

Eberline Services, Inc. has conducted many radiological surveys of soil contaminated with low and intermediate levels of radioactivity. Cleanup of these sites is a highly labor-intensive process requiring numerous personnel to conduct radiological surveys with portable handheld instruments. When contamination is encountered, an attempt is made to manually excise it. When surveys disclose larger areas of contamination, heavy equipment is used to remove the contaminated material. Since pinpoint excision with earthmoving equipment is difficult, large amounts of uncontaminated soil are removed along with the contaminant. Few sites have been characterized as uniformly and/or homogeneously contaminated above release criteria over the entire site area.

As a result, Eberline Services developed the Segmented Gate System (SGS) to physically separate and segregate radioactive material from otherwise "clean" soil (see figure below). The SGS removes only a minimal amount of clean soil with the radioactive particles, significantly reducing the overall amount of material requiring disposal. The SGS works by conveying radiologically contaminated feed material on moving conveyor belts under an array of sensitive, rapidly reacting radiation detectors. The moving material is assayed, and the radioactivity content is logged. Copyrighted computer software tracks the radioactive material as it is transported by the conveyor and triggers a diversion by one or more of the SGS chutes when the material reaches the end of the conveyor. Clean soil goes in one direction, and the contaminated material in another.



The key advantage to this system is automation, which affords a much higher degree of accuracy compared to manual methods. Contaminants can be isolated and removed by locating small particles of radioactive material dispersed throughout the soil. All of the soil is analyzed continuously during processing to document the level of radioactivity in the waste and to demonstrate that cleaned soil meets release criteria. This automation and analysis results in a significant cost reduction for special handling, packaging, and disposal of the site's radioactive waste.

The SGS locates, analyzes, and removes gamma-ray-emitting radionuclides from soil, sand, dry sludge, or any host matrix that can be transported by conveyor belts. The SGS can identify hot particles, which are assayed in units of picoCuries (pCi), and can quantify distributed radioactivity, which is assayed in units of pCi per gram (pCi/g) of host material. The lower limit of detection (LLD) for the system depends on the ambient radiation background, conveyor belt speed, thickness of host material on conveyor, and contaminant gamma ray energy and abundance. However, LLDs of 2 pCi/g for americium-241 and 4 pCi/g for radium-226 have been successfully demonstrated.

## **STATUS:**

This technology was accepted into the SITE Emerging Technology Program in July 1994. Pilot- and field-scale tests using Eberline Services' mobile equipment were initiated at a U.S. Department of Energy facility in March 1995.

A field test at the DOE site in Ashtabula, Ohio was conducted in October 1998. Soil containing thotium-232, radium-226, and uranium-238 was processed.

A similar system was operated by Eberline Services on Johnston Atoll in the mid-Pacific from January 1992 until November 1999 under contract to the U.S. Defense Threat Reduction Agency to process coral soil contaminated with plutonium and americium. The mobile SGS used at Ashtabula has also been deployed under the Department of Energy, Accelerated Site Technology Demonstration Program at Sandia National Laboratories, Los Alamos National Laboratory, Pantex Plant, Nevada Test Site-Tonapah Test Range, Idaho National Engineering and Environmental Laboratory, and Brookhaven National Laboratory.

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## ELECTROKINETICS, INC. (In Situ Bioremediation by Electrokinetic Injection)

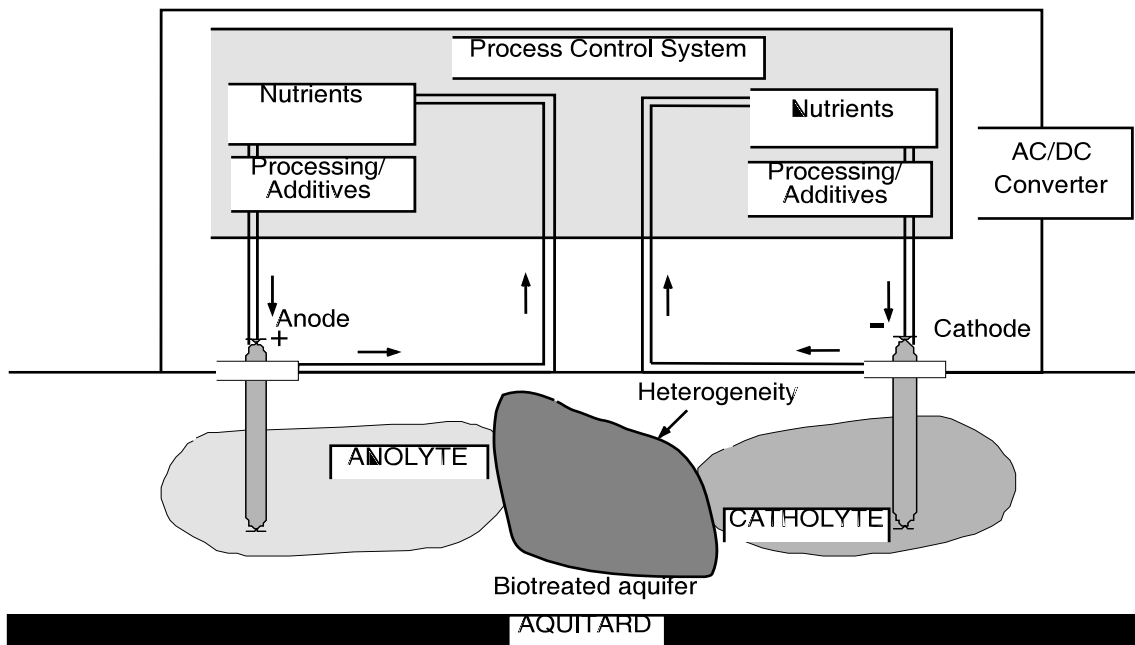
### TECHNOLOGY DESCRIPTION:

In situ bioremediation is the process of introducing nutrients into biologically active zones (BAZ). The nutrients are usually introduced by pumping recirculated groundwater through the BAZ, relying on hydraulic gradients or the permeability of the BAZ. However, heterogeneous aquifers often hinder the introduction of the nutrients. For example, areas with higher permeability result in preferential flow paths, leading to incomplete biological treatment in other areas. The inability to uniformly introduce nutrients and other additives, such as surfactants and cometabolites, is recognized as a hindrance to successful implementation of in situ bioremediation.

Electrokinetics, Inc. (Electrokinetics), has developed an electrokinetic remediation technology that stimulates and sustains in situ bioremediation for the treatment of organics.

The technology involves applying to soil or groundwater a low-level direct current (DC) electrical potential difference or an electrical current using electrodes placed in an open or closed flow arrangement. Groundwater or an externally supplied processing fluid is used as the conductive medium. The low-level DC causes physical, chemical and hydrological changes in both the waste and the conductive medium, thereby enabling uniform transport of process additives and nutrients into the BAZ. The process is illustrated in the diagram below.

Electrokinetic soil processing technologies were designed to overcome problems associated with heterogeneous aquifers, especially those problems that result in incomplete biological treatment. For example, the rate of nutrient and additive transport under electrical gradients is at least one order of magnitude greater than that achieved under hydraulic gradients.



Schematic Diagram of In Situ Bioremediation by Electrokinetic Injection

## WASTE APPLICABILITY:

In situ electrokinetic injection can be used for any waste that can be treated by conventional bioremediation techniques. The Electrokinetics, Inc. system facilitates in situ treatment of contaminated subsurface deposits, sediments, and sludges. The technology can also be engineered to remove inorganic compounds through electromigration and electroosmosis, while process additives and nutrients are added to the processing fluids to enhance bioremediation of organic compounds.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in 1995. Pilot-scale studies under the Emerging Technology Program will be used to develop operating parameters and to demonstrate the efficiency and cost-effectiveness of the technology during a full-scale application. The SITE evaluation may take place in 1999 at a military base or a U.S. Department of Energy (DOE) site.

In a Phase-I study conducted for DOE, Electrokinetics, Inc., demonstrated that nutrient and process additives could be transported in and across heterogeneous areas in aquifers at rates that could sustain in-situ bioremediation. During the study, ion migration rates, which were on the order of 8 to 20 centimeters per day, exceeded the electroosmotic rate, even in a kaolinite clay. The ion migration also produced a reasonably uniform distribution of inorganic nitrogen, sulfur, and phosphorous additives across the soil mass boundaries. These results are significant and demonstrate that electrokinetic injection techniques may potentially be used for the injection of diverse nutrients in low permeability soils as well as heterogeneous media. Electrokinetics, Inc., recently completed bench- and pilot-scale tests, which determined the feasibility of enhancing the bioremediation of trichloroethylene and toluene by electrokinetic injection. The process of in situ

bioremediation by electrokinetic injection was inspired by extensive research work conducted by Electrokinetics, Inc., using the electrochemical process to remediate soils contaminated with heavy metals and radionuclides. In 1994, Electrokinetics, Inc., was commissioned by the U.S. Department of Defense (DoD) to demonstrate its technology in a lead-contaminated creek bed at an inactive firing range in Fort Polk, Louisiana. The study was supported under the U.S. EPA SITE Demonstration Program. This pilot-scale field demonstration represents the first comprehensive scientific study worldwide for the application of electrokinetic separation technology applied to the remediation of heavy metals in soils. Electrokinetics, Inc., successfully removed up to 98 percent of the lead from the firing range soil and received the 1996 Small Business Innovation Research (SBIR) Phase II Quality Award from DoD for technical achievement.

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## ELECTROKINETICS, INC. (Electrokinetic Soil Processing)

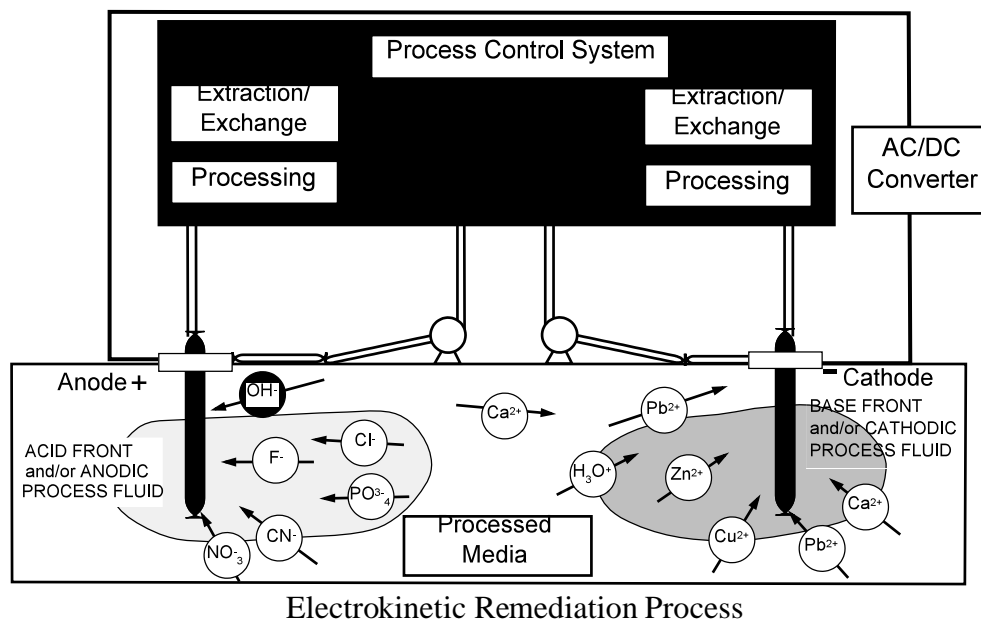
### TECHNOLOGY DESCRIPTION:

Electrokinetics, Inc.'s, soil processes extract or remediate heavy metals and organic contaminants in soils. The process can be applied in situ or ex situ with suitable chemical agents to optimize the remediation. For example, conditioning fluids such as suitable acids may be used for electrode (cathode) depolarization to enhance the electrodeposition of certain heavy metals.

The figure below illustrates the field-processing scheme and the flow of ions to respective boreholes (or trenches). The mechanism of electrokinetic soil remediation for the removal of toxic metals involves the application of an electrical field across the soil mass. An in-situ generated acid causes the solubilization of metal salts into the pore fluid. The free ions are then transported through the soil by electrical migration towards the electrode of opposing charge. Metal species with a positive charge are collected at the cathode, while species with a negative charge are collected at the anode.

An acid front migrates towards the negative electrode (cathode), and contaminants are extracted through electroosmosis (EO) and electromigration (EM). The concurrent mobility of the ions and pore fluid decontaminates the soil mass. Electrokinetic remediation is extremely effective in fine-grained soils where other techniques such as pump and treat are not feasible. This is due to the fact that the contaminants are transported under charged electrical fields and not hydraulic gradients.

Bench-scale results show that the process works in both unsaturated and saturated soils. Pore fluid flow moves from the positive electrodes (anodes) to the cathodes under the effect of the EO and EM forces. Electrode selection is important, since many metal or carbon anodes rapidly dissolve after contact with strong oxidants. When the removal of a contaminant is not feasible, the metal can be stabilized in-situ by injecting stabilizing agents or creating an electrokinetic "fence" (reactive treatment wall) that reacts with and immobilizes the contaminants.



## WASTE APPLICABILITY:

Electrokinetic soil processing extracts heavy metals, radionuclides, and other inorganic contaminants below their solubility limits. During bench-scale testing, the technology has removed arsenic, benzene, cadmium, chromium, copper, ethylbenzene, lead, mercury, nickel, phenol, trichloroethylene, toluene, xylene, and zinc from soils. Bench-scale studies under the SITE Emerging Technology Program demonstrated the feasibility of removing uranium and thorium from kaolinite.

Limited pilot-scale field tests resulted in lead and copper removal from clays and saturated and unsaturated sandy clay deposits. Treatment efficiency depended on the specific chemicals, their concentrations, and the buffering capacity of the soil. The technique proved 85 to 95 percent efficient when removing phenol at concentrations of 500 parts per million (ppm). In addition, removal efficiencies for lead, chromium, cadmium, and uranium at levels up to 2,000 micrograms per gram ranged between 75 and 98 percent.

## STATUS:

Based on results from the Emerging Technology Program, the electrokinetic technology was invited in 1994 to participate in the SITE Demonstration Program. For further information on the pilot-scale system, refer to the Emerging Technology Bulletin (EPA/540/F-95/504), which is available from EPA. The SITE demonstration began in July 1995 at an inactive firing range at the Fort Polk Army Ammunition Reservation in Louisiana. The soil at the site is contaminated with lead, copper, and zinc, which have accumulated over several decades. Concentrations of lead in the sandy clay soil range from 1,000 to 5,000 ppm and are less than 100 ppm at a 3-foot depth. A 20-foot by 60-foot area was remediated to a depth of 3 feet. This demonstration represents the first comprehensive study in the United States of an in situ electrokinetic separation technology applied to heavy metals in soils. Electrokinetics Inc. received the 1996 SBIR Phase II Quality Award from the Department of Defense for its technical achievement on this project.

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## ENERGIA, INC. (Reductive Photo-Dechlorination Treatment)

### TECHNOLOGY DESCRIPTION:

The Reductive Photo-Dechlorination (RPD) treatment uses ultraviolet (UV) light in a reducing atmosphere and at moderate temperatures to treat waste streams containing chlorinated hydrocarbons (CIHC). Because CIHCs are destroyed in a reducing environment, the only products are hydrocarbons and hydrogen chloride (HCl).

The RPD process is depicted in the figure below. The process consists of five main units: (1) input/mixer (2) photo-thermal chamber (3) HCl scrubber (4) separator and (5) products storage and recycling. Chlorinated wastes may be introduced into the process in one of three ways: vapor, liquid, or bound to an adsorbent, such as activated carbon.

Air laden with chlorocarbon vapors is first passed through a condenser, which removes chlorinated materials as liquids. Chlorocarbon liquids are fed into a vaporizer, mixed with a reducing gas, and passed into the photo-thermal chamber. Chlorinated contaminants adsorbed onto activated carbon are purged with reducing gas and mildly heated to induce vaporization. The ensuing vapors are then fed into the photo-thermal chamber.

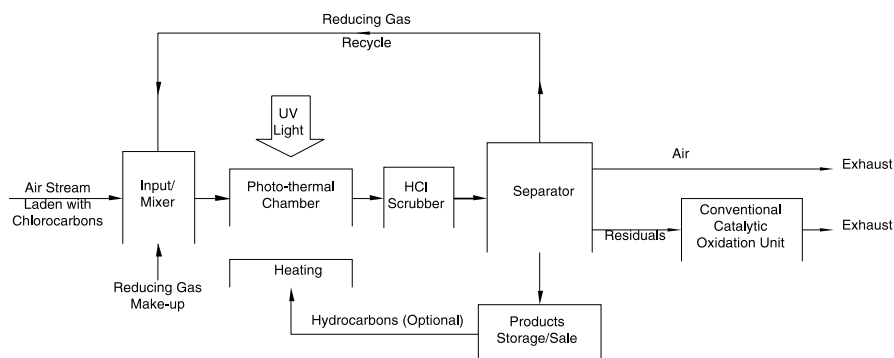
The photo-thermal chamber is the heart of the RPD process because all reactions central to the process occur in this chamber. Saturated, olefinic, or aromatic chlorocarbons with one or more carbon-chlorine bonds are exposed to UV light, heat, and a reducing

atmosphere, such as hydrogen gas or methane. According to ENERGIA, Inc., carbon-chlorine bonds are broken, resulting in chain-propagating hydrocarbon reactions. Chlorine atoms are eventually stabilized as HCl, which is easily removed in a scrubber. Hydrocarbons may hold their original structures, rearrange, cleave, couple, or go through additional hydrogenation. Hydrocarbons produced from the dechlorination of wastes include ethane, acetylene, ethene, and methane. Valuable hydrocarbon products can be stored, sold, or recycled as auxiliary fuel to heat the photo-thermal chamber.

### WASTE APPLICABILITY:

The RPD process is designed specifically to treat volatile chlorinated wastes in the liquid, gaseous, or adsorbed states. The RPD process was tested on methyl chloride, dichloromethane (DCM), chloroform, carbon tetrachloride, trichloroethane (TCA), dichloroethene (PCE), and trichloroethene (TCE).

Field applications include treatment of organic wastes discharged from soil vapor extraction operations, vented from industrial hoods and stacks, and adsorbed on activated carbon. The process can be used to (1) treat gas streams containing chlorinated hydrocarbons, and (2) pretreat gas streams entering catalytic oxidation systems by reducing chlorine content and protecting the catalyst against poisoning. In comparison to other photo-thermal processes (such as reductive photo-thermal oxidation [RPTO] and photo-



Reductive Photo-Dechlorination (RPD) Treatment

thermal oxidation [PTO]), the RPD process is mostly applicable to streams without air and very high concentrations of contaminants (bulk down to greater than 1 percent). At very low concentrations (parts per million) and in the presence of air, the other photo-thermal processes may more cos- effective.

## STATUS:

Bench-scale experiments were conducted on several contaminants (such as DCM, DCE, TCA, and TCE). Measurements of concentrations of parent compounds and products as a function of residence time were obtained at several test conditions. From these measurements, conversion and dechlorination efficiencies were determined at optimal operating conditions.

Experimental results on a representative chlorocarbon contaminant (TCA) are available in the Emerging Technology Bulletin (EPA/540/F-94/508). Greater than 99 percent conversion and dechlorination were demonstrated with high selectivity towards two saleable hydrocarbon products, ethane and methane. Similar favorable results were obtained for other saturated and unsaturated chlorocarbons treated by the RPD process.

Results of a cost analysis based on experimental data indicate that the RPD process is extremely cost competitive. For example, the cost of treating TCE concentrations of 1,000 ppm and 10,000 ppm is \$1.10 and \$0.25 per pound treated, respectively. The cost per 1,000 cubic feet of contaminated stream with 1,000 ppm is \$0.38 and \$0.88, respectively.

All technical data have been gathered and optimization has been completed. Design and assembly of a pilot-scale prototype are underway. The field demonstration may take place during 1999. The developer is seeking appropriate sites for field demonstration. After successful demonstration, the RPD process will be ready for full-scale commercialization.

The RPD technology has successfully completed the bench-scale developmental stage. Results are documented in the Emerging Technology Bulletin (EPA/540/F-94/508). Experimental results on a representative chlorocarbon contaminant (TCA) have demonstrated greater than 99% conversion and dechlorination, with high selectivity towards two saleable hydrocarbon products, ethane and methane. Similar favorable results have been obtained for other saturated and unsaturated chlorocarbons treated by the RPD process. Preliminary cost analysis shows that the process is extremely cost-competitive with other remedial processes; the estimated cost is less than \$1 per pound of treated chlorocarbon. Based on the bench-scale results, a pilot-scale prototype unit has been designed and constructed. Currently, Energia is seeking funds to demonstrate the RPD technology with the pilot-scale system. After a successful pilot-scale demonstration the RPD technology will be available for commercialization.

These processes will be available for commercialization after the completion of the field demonstration.

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## ENERGIA, INC.

### (Reductive Thermal and Photo-Thermal Oxidation Processes for Enhanced Conversion of Chlorocarbons)

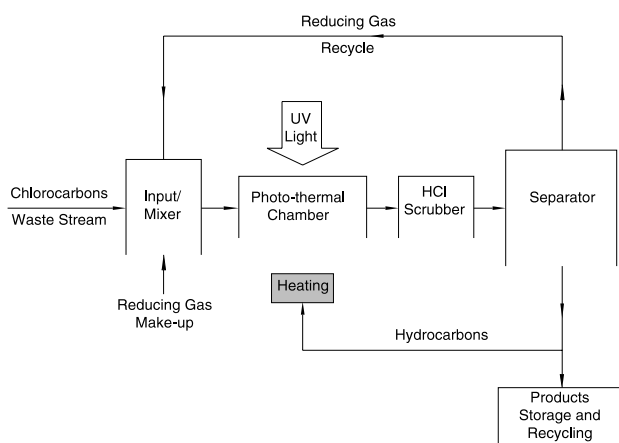
#### TECHNOLOGY DESCRIPTION:

Two innovative processes, Reductive Thermal Oxidation (RTO) and Reductive Photo-Thermal Oxidation (RPTO), are designed to safely and cost-effectively convert chlorinated hydrocarbons (CIHC) into environmentally benign and useful materials in the presence of a reducing atmosphere. Both processes have evolved from Energia, Inc.'s, Reductive Photo-Dechlorination (RPD) technology, which does not permit the presence of air (oxygen).

The RTO/RPTO processes treat air streams laden with CIHCs. RTO converts CIHCs at moderate temperatures by cleaving carbon-chlorine bonds in the absence of ultraviolet light. RPTO operates under similar conditions but in the presence of ultraviolet light. Subsequent reactions between ensuing radicals and the reducing gas result in chain-propagation reactions. The presence of air (oxygen) during the conversion process accelerates the overall reaction rate without significant oxidation. The final products are useful hydrocarbons (HC) and environmentally safe materials, including hydrogen chloride, carbon dioxide, and water.

The RTO/RPTO processes are shown in the figure below. The process consists of six main units: (1) input/mixer (2) photo-thermal chamber (3) scrubber (4) separator (5) product storage/sale and (6) conventional catalytic oxidation unit. Air laden with CIHCs is mixed with reducing gas and passed into a photo-thermal chamber, which is unique to the RTO/RPTO technology. In this chamber, the mixture is heated to moderate temperatures to sustain the radical chain reactions. Depending on the physical and chemical characteristics of the particular CIHCs being treated, conversion can take place in two ways: the RTO process is purely thermal, and the RPTO process is photo-thermal. After suitable residence time, HCl is removed by passing the stream through an aqueous scrubber. The stream can then be treated in an optional second stage, or it can be separated and sent to storage.

Excess reducing gas is recycled, and residual CIHCs, HCs, and CO<sub>2</sub> are either exhausted, or if needed, treated by catalytic oxidation. Volatile hydrocarbons can also be recycled as an energy source for process heating, if partial oxidation at the photo-thermal chamber does not generate enough heat.



**Reductive Thermal Oxidation (RTO)  
and Photo-Thermal Oxidation (RPTO) Process**

## **WASTE APPLICABILITY:**

This technology is designed to remove volatile hydrocarbons from air streams. Field applications include direct treatment of air streams contaminated with chlorocarbons, wastes discharged from soil vapor extraction or vented from industrial hoods and stacks, and those absorbed on granular activated carbon. M.L. ENERGIA, Inc., claims that the process can also be applicable for in situ treatment of sites containing contaminated surface waters and groundwaters. The process has not yet been tested on these sites.

## **STATUS**

This technology was accepted into the SITE Emerging Technology Program in July 1994. Laboratory-scale tests were conducted on two saturated CIHCs (dichloromethane and trichloroethane) and on two representatives of unsaturated CIHCs (1,2-dichloroethene and trichloroethene). The RTO/RPTO processes have demonstrated 99% or more conversion/dechlorination with high selectivity towards saleable hydrocarbon products (methane and ethane). Based on these results, a pilot-scale prototype has been designed and constructed. Preliminary pilot-scale tests have been performed and the results are very encouraging. Currently, funds are sought for a comprehensive field demonstration with the pilot-scale system, followed by performance evaluation and cost analysis.

These processes will be available for commercialization after the completion of the field demonstration.

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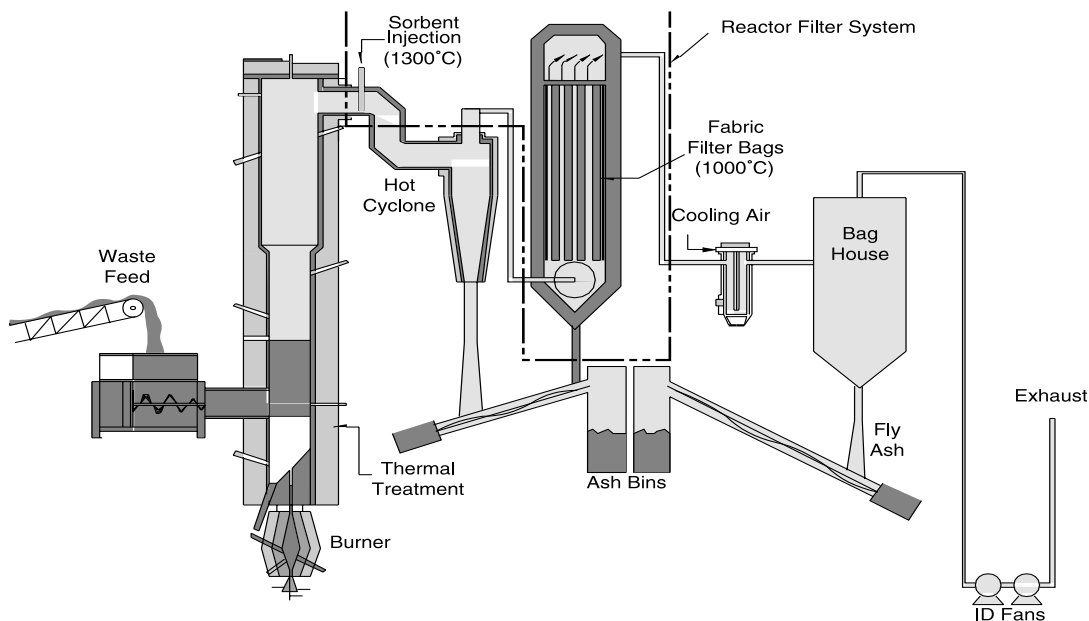
## ENERGY AND ENVIRONMENTAL RESEARCH CORPORATION (Reactor Filter System)

### TECHNOLOGY DESCRIPTION:

The Energy and Environmental Research Corporation (EER) Reactor Filter System (RFS) technology is designed to control gaseous and entrained particulate matter emissions from the primary thermal treatment of sludges, soils, and sediments. Most Superfund sites are contaminated with toxic organic chemicals and metals. Currently available thermal treatment systems for detoxifying these materials release products of incomplete combustion (PIC) and volatile toxic metals. Also, the large air pollution control devices (APCD) often required to control PICs and metals are generally not suitable for transport to remote Superfund sites. EER designed the RFS to avoid some of these logistical problems. The RFS uses a fabric filter installed immediately downstream of the thermal treatment process to control toxic metals, particulates, and unburned organic species.

The RFS involves the following three steps:

- First, solids are thermally treated with a primary thermal process, such as a rotary kiln, fluidized bed, or other system designed for thermal treatment.
- Next, a low-cost, aluminosilicate sorbent, such as kaolinite, is injected into the flue gases at temperatures near 1,300°C (2,370°F). The sorbent reacts with volatile metal species such as lead, cadmium, and arsenic in the gas stream and chemically adsorbs onto the surfaces of the sorbent particles. This adsorption forms insoluble, nonleachable alumino-silicate complexes similar to cementitious species.
- Finally, high-temperature fabric filtration, operating at temperatures up to 1,000°C (1,830°F), provides additional residence time for the sorbent/metal reaction to produce nonleachable



Example Application of RFS Equipment

by-products. This step also provides additional time for destruction of organic compounds associated with particulate matter, reducing ash toxicity. Because of the established link between PIC formation and gas-particle chemistry, this process can virtually eliminate potential polychlorinated dioxin formation.

The RFS may improve the performance of existing thermal treatment systems for Superfund wastes containing metals and organics. During incineration, hazardous organics are often attached to the particulate matter that escapes burning in the primary zone. The RFS provides sufficient residence time at sufficiently high temperatures to destroy such organics. Also, by increasing gas-solid contact parameters, the system can decrease metal emissions by preventing the release of metals as vapors or retained on entrained particles.

The figure on the previous page shows the RFS installed immediately downstream of the primary thermal treatment zone at EER's Spouted Bed Combustion Facility. Because the spouted bed generates a highly particulate-laden gas stream, a high-temperature cyclone is used to remove coarse particulate matter upstream of the RFS. Sorbent is injected into the flue gas upstream of the high temperature fabric filter. A conventional baghouse is available for comparison with RFS performance during the demonstration. However, the baghouse is not needed in typical RFS applications since the high-temperature filtration medium has shown similar performance to conventional fabric filtration media.

## **WASTE APPLICABILITY:**

The RFS is designed to remove entrained particulates, volatile toxic metals, and condensed-phase organics present in high-temperature (800 to 1,000°C) gas streams generated from the thermal treatment of contaminated soils, sludges, and sediments. Many conventional treatments can be combined with the RFS technology. Process residuals will consist of nonleachable particulates that are essentially free of organic compounds, thus reducing toxicity, handling risks, and landfill disposal.

## **STATUS:**

The RFS was accepted into the Emerging Technology Program in 1993. EER developed the pilot-scale process through a series of bench-scale screening studies, which were completed in September 1994. These screening studies guided the sorbent selection and operating conditions for the pilot-scale demonstration. The tests were completed in June 1996.

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## **ENERGY AND ENVIRONMENTAL RESEARCH CORPORATION (Hybrid Fluidized Bed System)**

### **TECHNOLOGY DESCRIPTION:**

The Hybrid Fluidized Bed (HFB) system treats contaminated solids and sludges by incinerating organic compounds and extracting and detoxifying volatile metals. The system consists of three stages: a spouted bed, a fluidized afterburner, and a high-temperature particulate soil extraction system.

First, the spouted bed rapidly heats solids and sludges to allow extraction of volatile organic and inorganic compounds. The spouted bed retains larger soil clumps until they are reduced in size but allows fine material to quickly pass through. This segregation process is beneficial because organic contaminants in fine particles vaporize rapidly. The decontamination time for large particles is longer due to heat and mass transfer limitations.

The central spouting region is operated with an inlet gas velocity of greater than 150 feet per second. This velocity creates an abrasion and grinding action, rapidly reducing the size of the feed materials through attrition. The spouted bed operates between 1,500 and 1,700°F under oxidizing conditions.

Organic vapors, volatile metals, and fine soil particles are carried from the spouted bed through an open-hole type distributor, which forms the bottom of the second stage, the fluidized bed afterburner. The afterburner provides sufficient retention time and mixing to incinerate the organic compounds that escape the spouted bed, resulting in a destruction and removal efficiency of greater than 99.99 percent. In addition, the afterburner contains bed materials that absorb metal vapors, capture fine particles, and promote formation of insoluble metal silicates. The bed materials are typically made of silica-supported bauxite, kaolinite, or lime.

In the third stage, the high-temperature particulate soil extraction system removes clean processed soil from the effluent gas stream with one or two hot cyclones. The clean soil is extracted hot to prevent unreacted volatile metal species from condensing in the soil. Off-gases are then quenched and passed through a conventional baghouse to capture the condensed metal vapors.

Generally, material handling problems create major operational difficulties for soil cleanup devices. The HFB system uses a specially designed auger feed system. Solids and sludges are dropped through a lock hopper system into an auger shredder, which is a rugged, low-revolutions-per-minute, feeding-grinding device. Standard augers are simple and reliable, but are susceptible to clogging from feed compression in the auger. In the HFB system, the auger shredder is close coupled to the spouted bed to reduce compression and clump formation during feeding. The close-couple arrangement locates the tip of the auger screw several inches from the internal surface of the spouted bed, preventing soil plug formation.

### **WASTE APPLICABILITY:**

This technology is applicable to soils and sludges contaminated with organic and volatile inorganic contaminants. Nonvolatile inorganics are not affected.

### **STATUS:**

This technology was accepted into the SITE Emerging Technology Program in January 1990. Design and construction of the commercial prototype HFB system and a limited shakedown are complete. The Emerging Technology Bulletin (EPA/540/F-93/508) is available from EPA.

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## ENVIRONMENTAL BIOTECHNOLOGIES, INC. (Microbial Composting Process)

### TECHNOLOGY DESCRIPTION:

Polycyclic aromatic hydrocarbons (PAH) are widespread pollutants found at creosote wood treatment sites and at manufacturing gas plants (MGP). Environments contaminated with these compounds are considered hazardous due to the potential carcinogenic effects of specific PAHs.

Environmental BioTechnologies, Inc. (EBT), investigated the bioremediation of contaminants associated with former MGP sites in a program cosponsored by the Electric Power Research Institute and the EPA. Initially, EBT screened over 500 fungal cultures (mostly brown and white rot fungi) for their ability to degrade PAHs and other organic pollutants. A group of 30 cultures were more intensely examined and several cultures were optimized for use in a soil composting process.

EBT conducted bench-scale treatability studies to assess the feasibility of PAH degradation in soil using a fungal augmented system designed to enhance the natural bioprocess. Results of one study are shown in the figure below. Concentrations of 10 PAHs were determined over a 59-day treatment period.

Some states have a soil treatment standard of 100 parts per million for total PAHs. EBT's fungal treatment process was able to reach this cleanup standard within a 5- to 6-week treatment period for one PAH-contaminated soil, as shown in the figure on the next page.

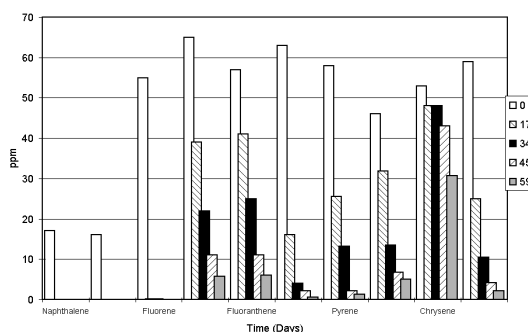
### WASTE APPLICABILITY:

One intended environmental application for this technology is the treatment of soil and sediment contaminated with coal tar wastes from former MGP sites. Soils at these sites are contaminated with PAHs and are difficult to remediate cost-effectively. EBT's fungal soil treatment process is projected to cost \$66 to \$80 per ton, which is more cost-effective than other technical approaches such as coburning in utility burners, thermal desorption, and incineration that are being considered by utility companies.

### STATUS:

EBT was accepted into the SITE Emerging Technology Program in 1993 and began laboratory studies in 1994. The project was completed in 1996. The overall project objectives were to (1) identify fungal and bacterial cultures that efficiently degrade coal tar wastes, and (2) develop and demonstrate a pilot-scale process that can be commercialized for utility industry applications.

EBT initially worked with PAH-spiked water and soils. EBT then tested, under optimized conditions, selected soil cultures from several MGP sites identified by New England Electric Services, a utility company sponsor. Testing identified several possibly superior fungal cultures to degrade PAHs. These cultures exhibited degradative preferences for either lower molecular weight or higher molecular weight PAHs, suggesting a consortia as a possible best



Fungal Degradation of Five PAHs in Soil Over A 59-Day Period

approach. These cultures were then examined in nutrient-supplemented systems to determine optimal PAH degradation rates.

A bench-scale composter system was used to determine optimal moisture content, soil amendment requirements, and inoculation procedures for accelerating degradation of PAHs. During the second year, small (less than 1 cubic yard) plots of MGP-site soil were used to test the optimized process in laboratory studies before a field demonstration is conducted. Results from the evaluation were published by EPA in 1997.

EBT has also conducted a bench-scale treatability study for a company in France to determine the feasibility of fungal PAH degradation in MGP soil. Results demonstrated an increased rate of biodegradation in the fungal-augmented system for all of the measured individual PAH compounds in the 80-day treatment period, compared with the natural, unamended system.

EBT conducted another lab study on oil refinery wastes which contained PAHs. the fungal composting process was able to remove 90% of the PAHs in an 18 week period. Based on the results obtained during the Emerging Technology Program stage, EBT's fungal technology has been accepted into the U.S. EPA SITE Demonstration Program.

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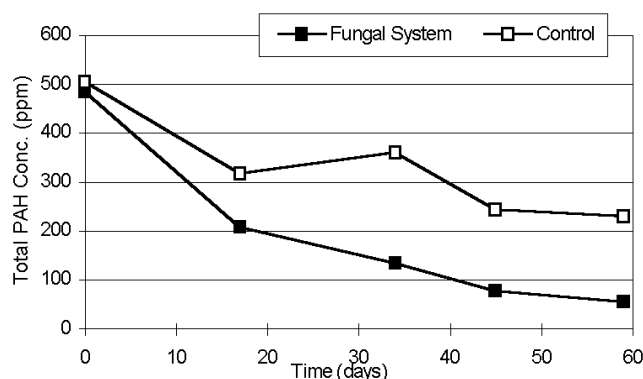
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Degradation of Total PAHs In Soil

## FERRO CORPORATION (Waste Vitrification Through Electric Melting)

### TECHNOLOGY DESCRIPTION:

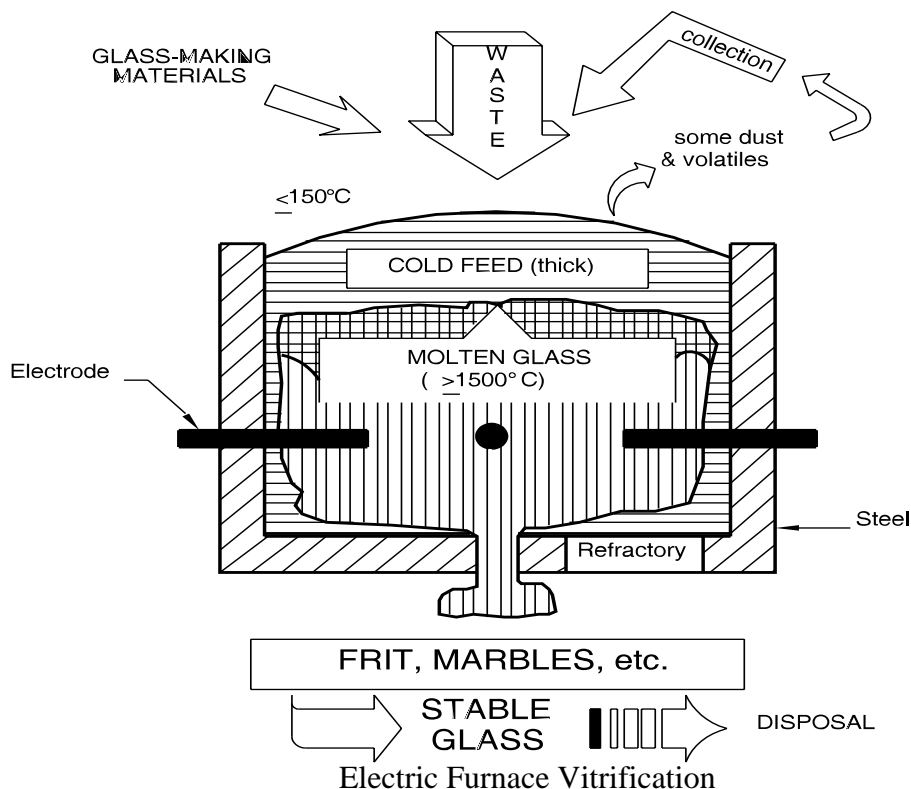
Vitrification technology converts contaminated soils, sediments, and sludges into oxide glasses, chemically rendering them nontoxic and suitable for landfilling as nonhazardous materials. Successful vitrification of soils, sediments, and sludges requires (1) development of glass compositions tailored to a specific waste, and (2) glass melting technology that can convert the waste and additives into a stable glass without producing toxic emissions.

In an electric melter, glass — an ionic conductor of relatively high electrical resistivity — stays molten with joule heating. Such melters process waste under a relatively thick blanket of feed material, which forms a counterflow scrubber that limits volatile emissions (see figure below).

Commercial electric melters have significantly reduced the loss of inorganic volatile constituents such as boric anhydride ( $B_2O_3$ ) or lead oxide ( $PbO$ ). Because of its low emission rate and small volume of exhaust gases, electric melting is a promising technology for incorporating waste into a stable glass matrix.

### WASTE APPLICABILITY:

Vitrification stabilizes inorganic components found in hazardous waste. In addition, the high temperature involved in glass production (about 1,500 °C) decomposes organics such as anthracene, bis(2-ethylhexyl phthalate), and pentachlorophenol in the waste. The decomposition products can easily be removed from the low volume of melter off-gas.



## STATUS:

Under the Emerging Technology Program, synthetic soil matrix IV (SSM-IV) has been developed and subjected to toxicity characteristic leaching procedure (TCLP) testing.

Ten independent replicates of the preferred composition produced the following results:

Metal	TCLP analyte concentration, parts per million	
	Remediation Limit	Mean of Glass Replicates
As	5	<0.100
Cd	1	<0.010
Cr	5	0.019
Cu	5	0.355
Pb	5	0.130
Ni	5	<0.010
Zn	5	0.293

SSM-IV and additives (sand, soda ash, and other minerals) required to convert SSM-IV to the preferred glass composition have been processed in a laboratory-scale electric melter. Three separate campaigns have produced glass at 17 pounds per hour at a fill of 67 percent SSM-IV and 33 percent glass-making additives. The TCLP mean analyte concentrations were less than 10 percent of the remediation limit at a statistical confidence of 95 percent. Ferro Corporation's experience indicates that this melting rate would produce an equivalent rate of 1 ton per hour in an electric melter used to treat wastes at a Superfund site. The Emerging Technology Bulletin (EPA/540/F-95/503) is available from EPA.

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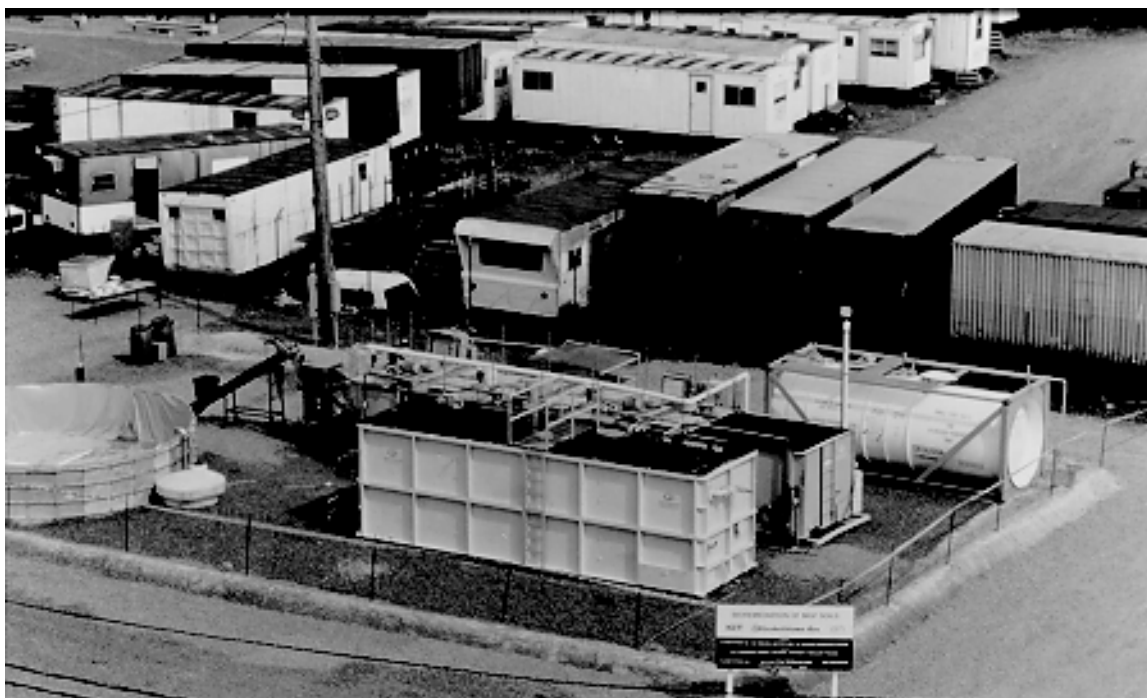
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## **GAS TECHNOLOGY INSTITUTE (Chemical and Biological Treatment)**

### **TECHNOLOGY DESCRIPTION:**

The Institute of Gas Technology (IGT) chemical and biological treatment (CBT) process remediates sludges, soils, groundwater, and surface water contaminated with organic pollutants, such as polynuclear aromatic hydrocarbons (PAH) and polychlorinated biphenyls (see photograph below). The treatment system combines two remedial techniques: (1) chemical oxidation as pretreatment, and (2) biological treatment using aerobic and anaerobic biosystems in sequence or alone, depending on the waste. The CBT process uses mild chemical treatment to produce intermediates that are biologically degraded, reducing the cost and risk associated with a more severe treatment process such as incineration.

During the pretreatment stage, the contaminated material is treated with a chemical reagent that degrades the organics to carbon dioxide, water, and partially oxidized intermediates. In the second stage of the CBT process, biological systems degrade the hazardous residual materials and the partially oxidized intermediates from the first stage. Chemically treated wastes are subjected to cycles of aerobic and anaerobic degradation if aerobic or anaerobic treatment alone is not sufficient. Several cycles of chemical and biological treatment are also used for extremely recalcitrant contaminants.



Chemical and Biological Treatment Process

## **WASTE APPLICABILITY:**

The CBT process can be applied to soils, sludges, groundwater, and surface water containing (1) high waste concentrations that would typically inhibit bioremediation, or (2) low waste concentrations for which bioremediation alone is too slow. The process is not adversely affected by radionuclides or heavy metals. Depending on the types of heavy metals present, these metals will bioaccumulate in the biomass, complex with organic or inorganic material in the soil slurries, or solubilize in the recycled water.

The CBT process can be applied to a wide range of organic pollutants, including alkenes, chlorinated alkenes, aromatics, substituted aromatics, and complex aromatics.

## **STATUS:**

IGT evaluated the CBT process for 2 years under the SITE Emerging Technology Program. The Emerging Technology Bulletin (EPA/540/F-94/540), which details results from the evaluation, is available from EPA. Based on results from the Emerging Technology Program, this technology was invited to participate in the SITE Demonstration Program.

Under the SITE Demonstration Program, IGT plans to conduct a full-scale demonstration of the CBT process on sediments containing PAHs. Different operating scenarios will be used to demonstrate how effectively the CBT process treats sediments in a bioslurry reactor. Several sites are being considered for the demonstration.

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## GAS TECHNOLOGY INSTITUTE (Fluid Extraction-Biological Degradation Process)

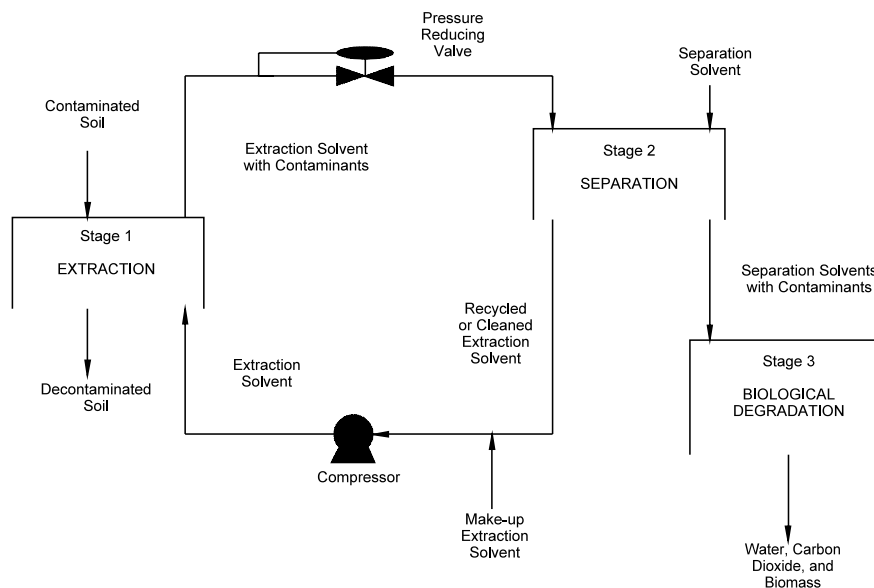
### TECHNOLOGY DESCRIPTION:

The three-step fluid extraction-biological degradation (FEBD) process removes organic contaminants from soil (see figure below). The process combines three distinct technologies: (1) fluid extraction, which removes the organics from contaminated solids; (2) separation, which transfers the pollutants from the extract to a biologically compatible solvent or activated carbon carrier; and (3) biological degradation, which destroys the pollutants and leaves innocuous end-products.

In the fluid extraction step, excavated soils are placed in a pressure vessel and extracted with a recirculated stream of supercritical or near-supercritical carbon dioxide. An extraction cosolvent may be added to enhance the removal of additional contaminants.

During separation, organic contaminants are transferred to a biologically compatible separation solvent such as water or a water-methanol mixture. The separation solvent is then sent to the final stage of the process, where bacteria degrade the waste to carbon dioxide and water. Clean extraction solvent is then recycled for use in the extraction stage.

Organic contaminants are biodegraded in aboveground aerobic bioreactors, using mixtures of bacterial cultures capable of degrading the contaminants. Selection of cultures is based on site contaminant characteristics. For example, if a site is mainly contaminated with polynuclear aromatic hydrocarbons (PAH), cultures able to metabolize or cometabolize these hydrocarbons are used. The bioreactors can be configured to enhance the rate and extent of biodegradation.



Fluid Extraction-Biological Degradation Process

Research continues on using bound activated carbon in a carrier system during the separation step. Bound activated carbon should allow high- pressure conditions to be maintained in the fluid extraction step, enhancing extraction efficiency and decreasing extraction time. Bound activated carbon should also limit the loss of carbon dioxide, thereby decreasing costs. The activated carbon containing the bound PAHs could then be treated in the biodegradation step by converting the carrier system to a biofilm reactor. These activated carbon carrier systems could then be recycled into the high-pressure system of the extraction and separation steps.

### **WASTE APPLICABILITY:**

This technology removes organic compounds from contaminated solids. It is more effective on some classes of organics, such as hydrocarbons (for example, gasoline and fuel oils) than on others, such as halogenated solvents and polychlorinated biphenyls. The process has also been effective in treating nonhalogenated aliphatic hydrocarbons and PAHs.

### **STATUS:**

This technology was accepted into the SITE Emerging Technology Program in June 1990. The Institute of Gas Technology has evaluated all three stages of the technology with soils from a Superfund site and from three town gas sites. These soils exhibited a variety of physical and chemical characteristics. Approximately 85 to 99 percent of detectable PAHs, including two- to six-ring compounds, were removed from the soils.

The measurable PAHs were biologically converted in both batch-fed and continuously fed, constantly stirred tank reactors. The conversion rate and removal efficiency were high in all systems. The PAHs were biologically removed or transformed at short hydraulic retention times. All PAHs, including four- to six-ring compounds, were susceptible to biological removal.

Results from this project were published in the Emerging Technology Bulletin (EPA/540/F-94/501), which is available from EPA. An article was submitted to the *Journal of Air and Waste Management*.

Potential users of this technology have expressed interest in continuing research. This technology has been invited to participate in the SITE Demonstration Program. The technology would be able to remediate town gas sites, wood treatment sites, and other contaminated soils and sediments.

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## **GAS TECHNOLOGY INSTITUTE**

### **(Fluidized-Bed/Cyclonic Agglomerating Combustor)**

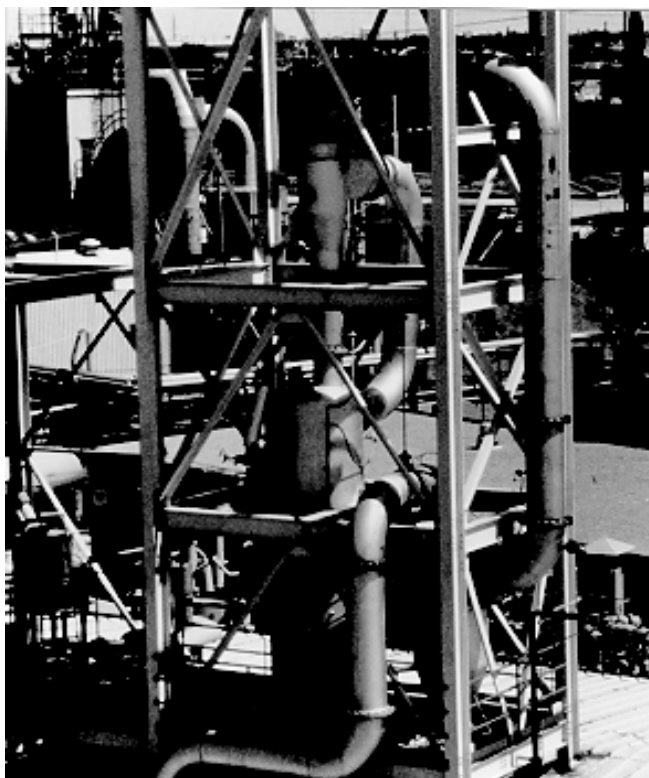
#### **TECHNOLOGY DESCRIPTION:**

The Institute of Gas Technology (IGT) has developed a two-stage, fluidized-bed/cyclonic agglomerating combustor (AGGCOM) based on a combination of IGT technologies. In the combined system, solid, liquid, and gaseous organic wastes can be efficiently destroyed. Solid, nonvolatile, inorganic contaminants are combined within a glassy matrix consisting of discrete pebble-sized agglomerates that are suitable for disposal in a landfill or use as an aggregate.

The first stage of the combustor is an agglomerating fluidized-bed reactor, which can operate under substoichiometric conditions or with excess air. This system can operate from low temperature (desorption) to high temperature (agglomeration). This system can also gasify materials with high calorific values (for

example, municipal solid wastes). With a unique fuel and air distribution, most of the fluidized bed is maintained at 1,500° to 2,000°F, while the central hot zone temperature can be varied between 2,000° and 3,000°F.

When contaminated soils and sludges are fed into the fluidized bed, the combustible fraction of the waste is rapidly gasified and combusted. The solid fraction, containing inorganic and metallic contaminants, undergoes a chemical transformation in the hot zone and is agglomerated into glassy pellets. These pellets are essentially nonleachable under the conditions of the toxicity characteristic leaching procedure (TCLP). The product gas from the fluidized bed may contain unburned hydrocarbons, furans, dioxins, and carbon monoxide, as well as carbon dioxide and water, the products of complete combustion.



AGGCOM Pilot Plant

The product gas from the fluidized bed is fed into the second stage of the combustor, where it is further combusted at a temperature of 1,800° to 2,400°F. The second stage is a high-intensity cyclonic combustor and separator that provides sufficient residence time (0.25 second) to oxidize carbon monoxide and organic compounds to carbon dioxide and water vapor. This stage has a combined destruction and removal efficiency of greater than 99.99 percent. Volatilized metals are collected downstream in the flue gas scrubber condensate.

The two-stage AGGCOM process is based on IGT's experience with other fluidized-bed and cyclonic combustion systems. The patented sloping-grid design and ash discharge port in this process were initially developed for IGT's U-GAS coal gasification process. The cyclonic combustor and separator is a modification of IGT's low-emissions combustor.

### **WASTE APPLICABILITY:**

The two-stage AGGCOM process can destroy organic contaminants in gaseous, liquid, and solid wastes, including soils and sludges. Gaseous wastes can be fired directly into the cyclonic combustor. Liquid, sludge, and solid wastes can be co-fired directly into the fluidized bed. Solid particles must be less than about 6 millimeters to support fluidized bed operation; therefore, certain wastes may require grinding or pulverization prior to remediation.

Because the solid components in the waste are heated above fusion temperature during the agglomeration process, metals and other inorganic materials are encapsulated and immobilized within the glassy matrix.

### **STATUS:**

This technology was accepted into the SITE Emerging Technology Program in July 1990. Tests conducted in the batch, 6-inch-diameter fluidized bed have demonstrated that agglomerates can be formed from

the soil. The agglomerates, produced at several different operating conditions from soil spiked with lead and chromium compounds, passed the TCLP test for leachability.

A pilot-scale combustor with a capacity of 6 tons per day has been constructed (see photograph on previous page), and testing has produced samples of agglomerated soil. Future testing will focus on sustained and continuous operation of the pilot-scale plant using different types of soil, as well as other feedstocks. Tests with organic and inorganic hazardous waste surrogates admixed with the feed soil will also be conducted. A final report on the project has been submitted to EPA.

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## GAS TECHNOLOGY INSTITUTE (Supercritical Extraction/Liquid Phase Oxidation)

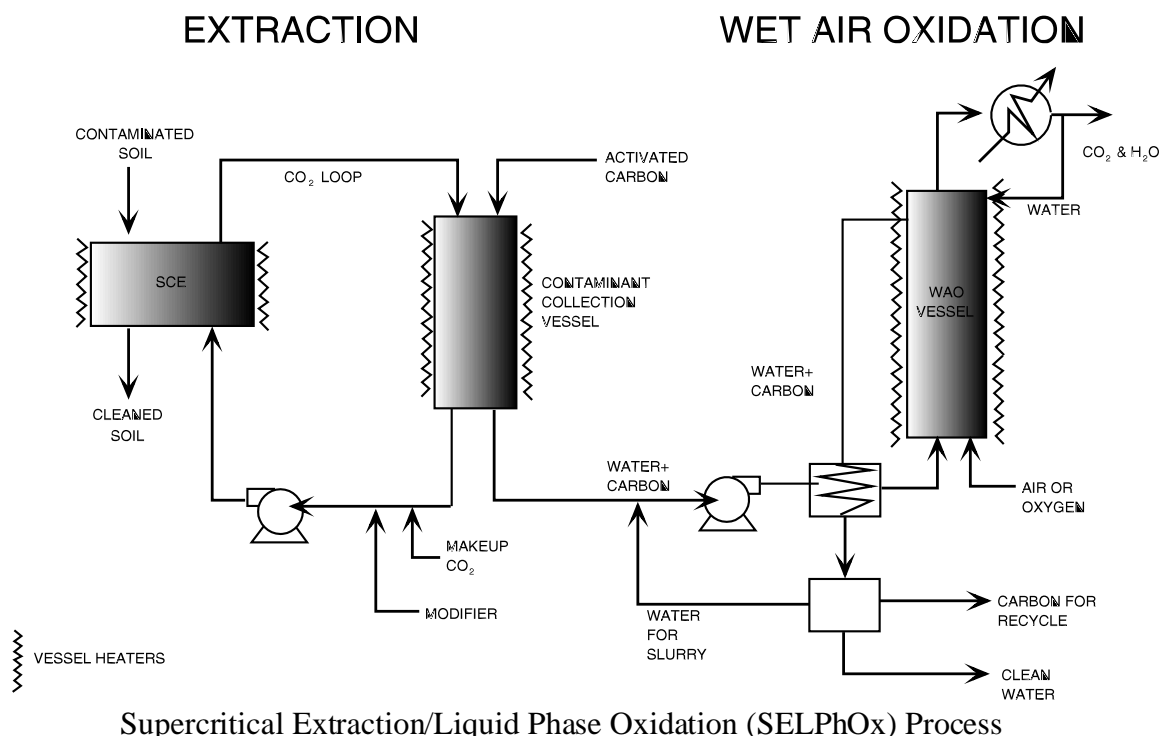
### TECHNOLOGY DESCRIPTION:

The Institute of Gas Technology's (IGT) Supercritical Extraction/Liquid Phase Oxidation (SELPPhOx) process (see figure below) removes organic contaminants from soils and sludges and destroys them. SELPhOx combines two processing steps: (1) supercritical extraction (SCE) of organic contaminants, and (2) wet air oxidation (WAO) of the extracted contaminants. The two-step process, linked by a contaminant collection stage, offers great flexibility for removing and destroying both high and low concentrations of organic contaminants.

Combining SCE and WAO in a single two-step process allows development of a highly efficient and economical process for remediating contaminated soils. Supercritical extraction with carbon dioxide ( $\text{CO}_2$ ) removes organic contaminants from the soil

while leaving much of the original soil organic matrix in place. The contaminants are collected on activated carbon in a contaminant collection vessel. The activated carbon with sorbed contaminants is then transported in an aqueous stream to a WAO reactor for destruction. Concentrating the organic contaminants on activated carbon in water provides a suitable matrix for the WAO feed stream and improves process economics by decreasing WAO reactor size. The activated carbon is regenerated in the WAO reactor with minimal carbon loss and can be recycled to the contaminant collection vessel.

The SELPhOx process requires only water, air, makeup activated carbon, and the extractant ( $\text{CO}_2$ ). Primary treatment products include cleaned soil, water, nitrogen (from the air fed to the WAO step), and  $\text{CO}_2$ . Organic sulfur, nitrogen, and chloride compounds that may be present in the original soil or sludge matrix are



transformed to relatively innocuous compounds in the product water. These compounds include sulfuric acid and hydrogen chloride, or their salts. The treated soil can be returned to the original site, and the water can be safely discharged after thermal energy recovery and minor secondary treatment. The gas can be depressurized by a turbo expander for energy recovery and then vented through a filter.

### **WASTE APPLICABILITY:**

The SELPhOx process removes organic contaminants from soils and sludges, including chlorinated and nonchlorinated polynuclear aromatic hydrocarbons (PAH), polychlorinated biphenyls, and other organic contaminants. The process is targeted toward sites that are contaminated with high levels of these organics (hot spots).

The SELPhOx process was accepted into the SITE Emerging Technology Program in July 1994. The primary objectives of the project are to (1) evaluate SCE's contaminant removal efficiency, (2) determine the potential for CO<sub>2</sub> recovery and reuse, and (3) determine destruction efficiencies of extracted contaminants in the WAO process. Analytical results from the project will provide the necessary information for the full-scale process design.

Laboratory-scale SCE tests have been completed using soils contaminated with PAHs. Operating conditions for the SCE stage and the activated carbon adsorption stage have been selected. A transportable field test unit was constructed and tested with PAH-contaminated soil. The final report has been submitted by the developer.

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## GENERAL ATOMICS, NUCLEAR REMEDIATION TECHNOLOGIES DIVISION (Acoustic Barrier Particulate Separator)

### TECHNOLOGY DESCRIPTION:

The acoustic barrier separates particulates in a high temperature gas flow. The separator produces an acoustic waveform directed against the gas flow, causing particulates to move opposite the flow. The particulates drift to the wall of the separator, where they aggregate with other particulates and precipitate into a collection hopper. The acoustic barrier particulate separator differs from other separators by combining both high efficiency and high temperature capabilities.

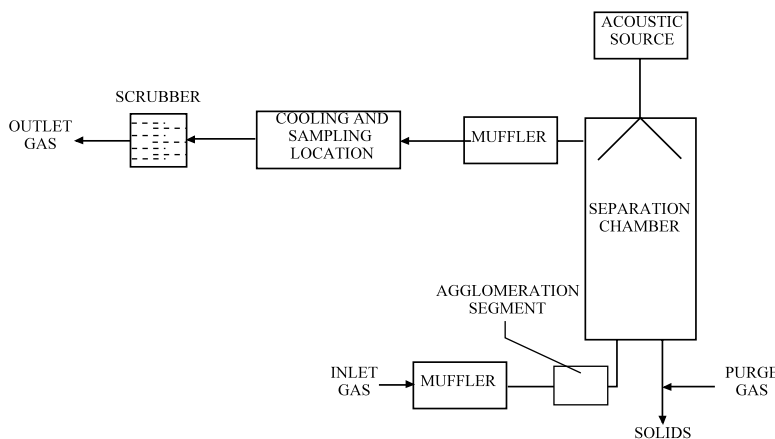
The figure below presents a conceptual design. High temperature inlet gas flows through a muffler chamber and an agglomeration segment before entering the separation chamber. In the separation chamber, particulates stagnate due to the acoustic force and then drift to the chamber wall, where they collect as a dust cake that falls into a collection hopper. The solids are transported from the collection hopper by a screw-type conveyor against a clean purge gas counterflow. The purge gas cools the solids and guards against contamination of particulates by inlet-gas volatiles in the process stream.

The gas flows past the acoustic source and leaves the separation chamber through an exit port. The gas then passes through another muffler chamber and flows through sections where it is allowed to cool and any remaining gas-borne particulate samples are collected. Finally, the gas is further scrubbed or filtered as necessary before it is discharged.

The separator can remove the entire range of particle sizes; it has a removal efficiency of greater than 90 percent for submicron particles and an overall removal efficiency of greater than 99 percent. Due to the large diameter of the separator, the system is not prone to fouling.

### WASTE APPLICABILITY:

This technology can treat off-gas streams from thermal desorption, pyrolysis, and incineration of soil, sediment, sludges, other solid wastes, and liquid wastes. The acoustic barrier particulate separator is a high-temperature, high-throughput process with a high removal efficiency for fine dust and fly ash. It is particularly suited for thermal processes where high temperatures must be maintained to prevent



Acoustic Barrier Particulate Separator

condensation onto particulates. Applications include removal of gas-borne solids during thermal treatment of semivolatile organics, such as polychlorinated biphenyls, and gas-phase separation of radioactive particles from condensible hazardous materials.

### **STATUS:**

The acoustic barrier particulate separator was accepted into the SITE Emerging Technology Program in 1993. The principal objective of this project will be to design, construct, and test a pilot-scale acoustic barrier particulate separator that is suitable for parallel arrangement into larger systems. The separator will be designed for a flow of 300 cubic feet per minute and will be tested using a simulated flue gas composed of heated gas and injected dust.

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## **GEO-MICROBIAL TECHNOLOGIES, INC.**

### **(Metals Release and Removal from Wastes)**

#### **TECHNOLOGY DESCRIPTION:**

Geo-Microbial Technologies, Inc., has developed an anaerobic biotreatment technology to release metals from liquefaction catalyst wastes. Such wastes are derived from spent coal and are also contaminated with complex organic compounds. The anaerobic metals release (AMR) technology may be adapted to treat other wastes contaminated with metals.

Current biohydrometallurgy systems use aerobic acidophilic bacteria, which oxidize mineral sulfides while making metals soluble and forming large amounts of acid. This aerobic process can result in acidic drainage from natural sources of metal sulfides. For example, acidophilic bacteria convert the pyrite and iron-containing minerals in coal into oxidized iron and sulfuric acid. The acid then makes the pyrite and other sulfide minerals more soluble resulting in stream and lake contamination due to acidification and an increase in soluble heavy metals.

The AMR technology operates anaerobically and at a near-neutral pH, employing anaerobic *Thiobacillus* cultures in conjunction with heterotrophic denitrifying bacterial cultures. The diverse culture of denitrifying bacteria consumes and treats multiple carbon sources, including some organic pollutants.

The anaerobic environment can be adjusted by introducing low levels of nitrate salts that function as an electron acceptor in the absence of oxygen. The nitrate salts provide an alternate electron acceptor and selectively enhance the remineralization process of the inherent denitrifying microflora.

This process increases the population of the denitrifying bacterial population that releases the metals. Soils containing the released metals are then flooded with the dilute nitrate solutions. The improved anaerobic leaching solutions permeate the soils, allowing the microbial activity to make the metals soluble in the leachate. The nitrate concentration is adjusted so that the effluent is free of nitrate and the nitrate concentration is monitored so that the process operation can be closely controlled. Soluble metals in the leachate are easily recaptured, and the metal-free effluent is recycled within the process. The nitrate-based ecology of the process also has the added advantage of decreasing levels of sulfate-reducing bacteria and sulfide generation.

The versatility and low operating constraints of the AMR technology offer multiple process options. The technology can be adapted for in situ flooding or modified to flood a waste pile in a heap-leaching operation. The elimination of any aeration requirement also allows the process to be designed and considered for bioslurry applications. As a result, the technology offers a greater range of treatment applications for environmental waste situations that are often considered difficult to treat.

#### **WASTE APPLICABILITY:**

The AMR technology targets toxic metal-contaminated soils, sludges, and sediments, which can also be contaminated with other wastes, including hydrocarbons and organic pollutants. While metals are the primary pollutant treated, the biological system is also designed to degrade and remove associated organic contaminants.

## **STATUS:**

The technology was accepted into the SITE Emerging Technology Program in July 1994. Studies under the Emerging Technology Program will evaluate how effectively the AMR technology removes metals from soil.

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**HARDING ESE, A MACTEC COMPANY**  
(formerly ABB Environmental Services, Inc.)  
(Two-Zone, Plume Interception, In Situ Treatment Strategy)

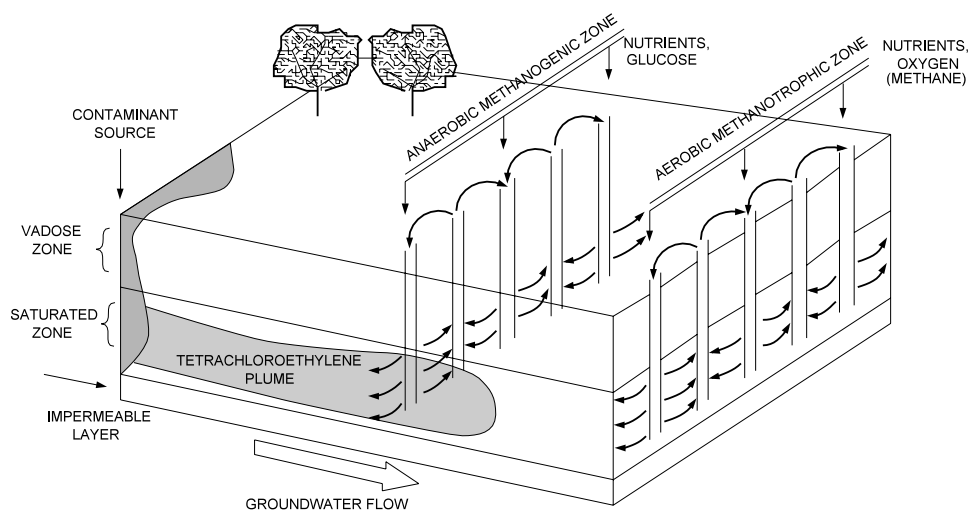
**TECHNOLOGY DESCRIPTION:**

The two-zone, plume interception, in situ treatment strategy is designed to treat chlorinated and nonchlorinated organic compounds in saturated soils and groundwater using a sequence of anaerobic and aerobic conditions (see figure below). The in situ anaerobic and aerobic system constitutes a treatment train that biodegrades a wide assortment of chlorinated and nonchlorinated compounds.

When applying this technology, anaerobic and aerobic conditions are produced in two distinct, hydraulically controlled, saturated soil zones. Groundwater passes through each zone as it is recirculated through the treatment area. The first zone, the anaerobic zone, is designed to partially dechlorinate highly chlorinated solvents such as tetrachloroethene (PCE), trichloroethene (TCE), and 1,1,1-trichloroethane with natural biological processes. The second zone, the aerobic zone, is designed to biologically oxidize the partially dechlorinated products from the first zone, as well as other compounds that were not susceptible to the anaerobic treatment phase.

Anaerobic conditions are produced or enhanced in the first treatment zone by introducing a primary carbon source, such as lactic acid, and mineral nutrients, such as nitrogen and phosphorus. When proper anaerobic conditions are attained, the target contaminants are reduced. For example, PCE is dechlorinated to TCE, and TCE is dechlorinated to dichloroethene (DCE) and vinyl chloride. Under favorable conditions, this process can completely dechlorinate the organics to ethene and ethane.

Aerobic conditions are produced or enhanced in the second treatment zone by introducing oxygen, mineral nutrients such as nitrogen and phosphorus, and possibly an additional carbon source, such as methane (if an insufficient supply of methane results from the upstream, anaerobic zone). When proper aerobic conditions are attained in this zone, partially dechlorinated products and other target compounds from the first zone are oxidized. For example, less-chlorinated ethenes such as DCE and vinyl chloride are cometabolized during the aerobic microbiological degradation of methane.



Two-Zone, Plume Interception, In Situ Treatment Strategy

The treatment strategy is designed to biologically remediate subsoils by enhancing indigenous microorganism activity. If indigenous bacterial populations do not provide the adequate anaerobic or aerobic results, specially adapted cultures can be introduced to the aquifer. These cultures are introduced using media-filled trenches that can support added microbial growth.

## **WASTE APPLICABILITY:**

The two-zone, plume interception, in situ treatment strategy is designed to treat groundwater and saturated soils containing chlorinated and nonchlorinated organic compounds.

## **STATUS:**

The two-zone, plume interception, in situ treatment strategy was accepted into the SITE Emerging Technology Program in July 1989. Optimal treatment parameters for field testing were investigated in bench-scale soil aquifer simulators. The objectives of bench-scale testing were to (1) determine factors affecting the development of each zone, (2) evaluate indigenous bacterial communities, (3) demonstrate treatment of chlorinated and nonchlorinated solvent mixtures, and (4) develop a model for the field remediation design. The Emerging Technology Bulletin (EPA/540/F-95/510), which details the bench-scale testing results, is available from EPA.

A pilot-scale field demonstration system was installed at an industrial facility in Massachusetts. Pilot-scale testing began in September 1996. Results from this testing indicate the following:

- The reductive dechlorination of PCE and TCE to DCE, VC, and ethene has been accomplished primarily by sulfate-reducing bacteria.
- A time lag of about 4 months was required before significant reductive dechlorination occurred. This corresponded to the time and lactic acid dosing required to reduce the redox to about -100 throughout the treatment cell.
- Sequential anaerobic-aerobic (Two-Zone) biodegradation of PCE and its degradation products appear to be a viable and cost-effective treatment technology for the enhancement of natural reductive dechlorination processes.

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## HIGH VOLTAGE ENVIRONMENTAL APPLICATIONS, INC. (High-Energy Electron Beam Irradiation)

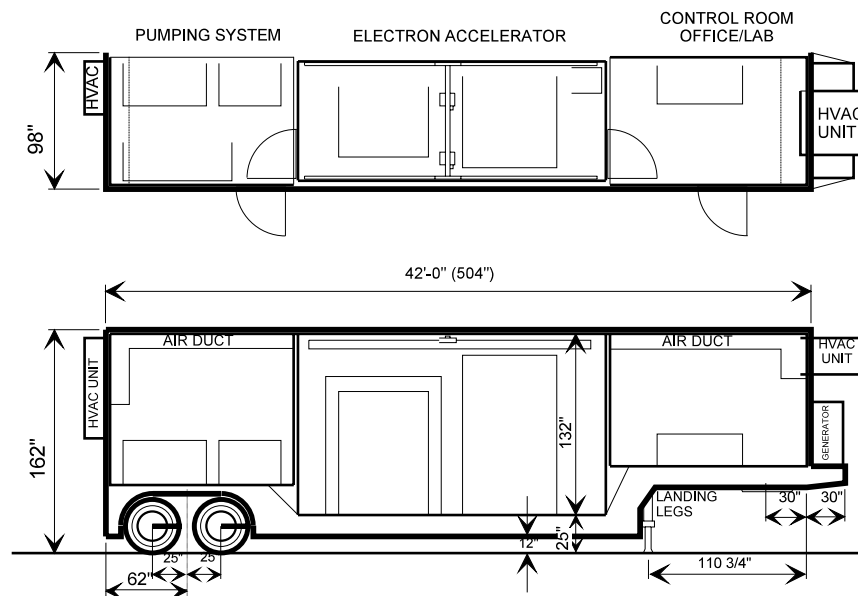
### TECHNOLOGY DESCRIPTION:

The high-energy electron beam irradiation technology is a low-temperature method for destroying complex mixtures of hazardous organic chemicals in hazardous wastes. These wastes include slurried soils, river or harbor sediments, and sludges. The technology can also treat contaminated soils and groundwater.

The figure below illustrates the mobile electron beam treatment system. The system consists of a computer-automated, portable electron beam accelerator and a delivery system. The 500-kilovolt electron accelerator produces a continuously variable beam current from 0 to 40 milliamperes. At full power, the system is rated at 20 kilowatts. The waste feed rate and beam current can be varied to obtain doses of up to 2,000 kilorads in a one-pass, flow-through mode.

The system is trailer-mounted and is completely self-contained, including a 100-kilowatt generator for remote locations or line connectors where power is available. The system requires only a mixing tank to slurry the treatable solids. The system also includes all necessary safety checks.

The computerized control system continuously monitors the waste feed rate, absorbed dose, accelerator potential, beam current, and all safety shutdown features. The feed rate is monitored with a calibrated flow valve. The absorbed dose is estimated based on the difference in the temperature of the waste stream before and after irradiation. The system is equipped with monitoring devices that measure the waste stream temperature before and after irradiation. Both the accelerating potential and the beam current



Mobile Electron Beam Treatment System

are obtained directly from the transformer. Except for slurring, this technology does not require any pretreatment of wastes.

### **WASTE APPLICABILITY:**

This technology treats a variety of organic compounds, including wood-treating chemicals, pesticides, insecticides, petroleum residues, and polychlorinated biphenyls (PCB) in slurried soils, sediments, and sludges.

### **STATUS:**

High Voltage Environmental Applications, Inc. (HVEA), was accepted into the SITE Emerging Technology Program in 1993. Under this program, HVEA will demonstrate its mobile pilot plant on soils, sediments, or sludges at various hazardous waste sites. Candidate sites are being identified. On-site studies will last up to 2 months.

Initial studies by HVEA have shown that electron beam irradiation effectively removes 2,4,6-trinitrotoluene from soil slurries.

As part of the Emerging Technology Program, HVEA has identified 350 tons of soil contaminated with an average Aroclor 1260 concentration of about 1,000 milligrams per kilogram. A small 1-ton feasibility study was conducted in August 1995. After results are available from the 1-ton study, HVEA plans to make its mobile unit available for full-scale remediations.

In a recent bench-scale study, a multisource hazardous waste leachate containing 1 percent dense nonaqueous phase liquid was successfully treated. In another bench-scale study, a leachate containing a light nonaqueous phase liquid contaminated with PCBs was treated to F039 standards.

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## IT CORPORATION (Batch Steam Distillation and Metal Extraction)

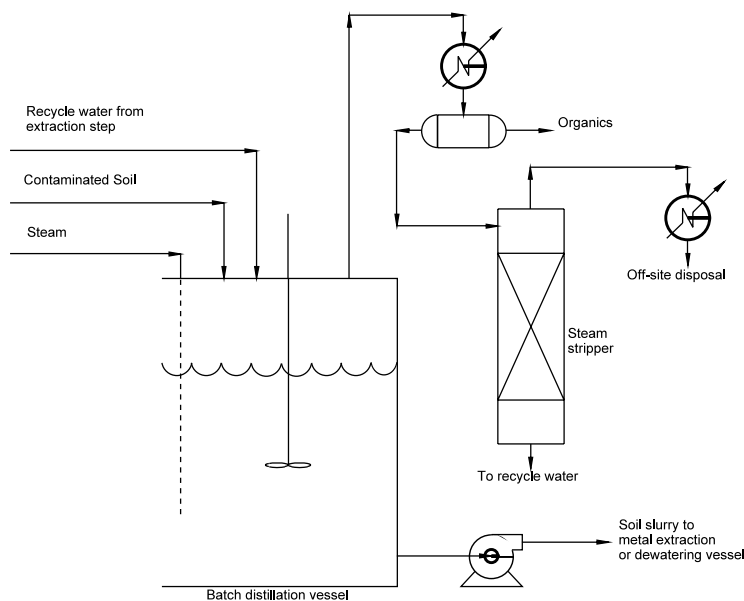
### TECHNOLOGY DESCRIPTION:

The batch steam distillation and metal extraction treatment process is a two-stage system that treats soils contaminated with organics and inorganics. This system uses conventional, readily available process equipment and does not produce hazardous combustion products. Hazardous materials are separated from soils as concentrates, which can then be disposed of or recycled. The treated soil can be returned to the site.

During treatment, waste soil is slurried in water and heated to 100°C. This heat vaporizes volatile organic compounds (VOC) and produces an amount of steam equal to 5 to 10 percent of the slurry volume. Resulting vapors are condensed and decanted to separate organic contaminants from the aqueous phase. Condensed water from this step can be recycled through the system after soluble organics are removed. The soil is then transferred as a slurry to the metal extraction step.

In the metal extraction step, the soil slurry is washed with hydrochloric acid. Subsequent countercurrent batch washing with water removes residual acid from the soil. The solids are then separated from the final wash solution by gravimetric sedimentation. Most heavy metals are converted to chloride salts in this step. The acid extract stream is then routed to a batch steam distillation system, where excess hydrochloric acid is recovered (see figure below). Bottoms from the still, which contain heavy metals, are precipitated as hydroxide salts and drawn off as a sludge for off-site disposal or recovery.

As a batch process, this treatment technology is targeted at sites with less than 5,000 tons of soil requiring treatment. Processing time depends on equipment size and batch cycle times; about one batch of soil can be treated every 4 hours.



**Batch Steam Distillation Step**

## WASTE APPLICABILITY:

This process may be applied to soils and sludges contaminated with organics, inorganics, and heavy metals.

## STATUS:

The batch steam distillation and metal extraction process was accepted into the SITE Emerging Technology Program in January 1988. The evaluation was completed in 1992. The Emerging Technology Bulletin (EPA/540/F-95/509), which details results from the test, is available from EPA.

Under the program, three pilot-scale tests have been completed on three soils, for a total of nine tests. The removal rates for benzene, toluene, ethylbenzene, and xylene were greater than 99 percent. The removal rates for chlorinated solvents ranged from 97 percent to 99 percent. One acid extraction and two water washes resulted in a 95 percent removal rate for heavy metals. Toxicity characteristic leaching procedure tests on the treated soils showed that soils from eight of the nine tests met leachate criteria. Data were also collected on the recovery rate for excess acid and the removal rate for precipitation of heavy metals into a concentrate.

Estimated treatment costs per ton, including capital recovery, for the two treatment steps are as follows:

Batch Steam Distillation	
500-ton site	\$299-393/ton
2,500-ton site	\$266-350/ton
Metals Extraction (including acid recovery)	
500-ton site	\$447-619/ton
2,500-ton site	\$396-545/ton

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## IT CORPORATION (Chelation/Electrodeposition of Toxic Metals from Soils)

### TECHNOLOGY DESCRIPTION:

IT Corporation has conducted laboratory-scale research on an innovative process that removes heavy metals from contaminated soils and sludges by forming a soluble chelate. The metals and the chelating agent are then separated from the soils and recovered.

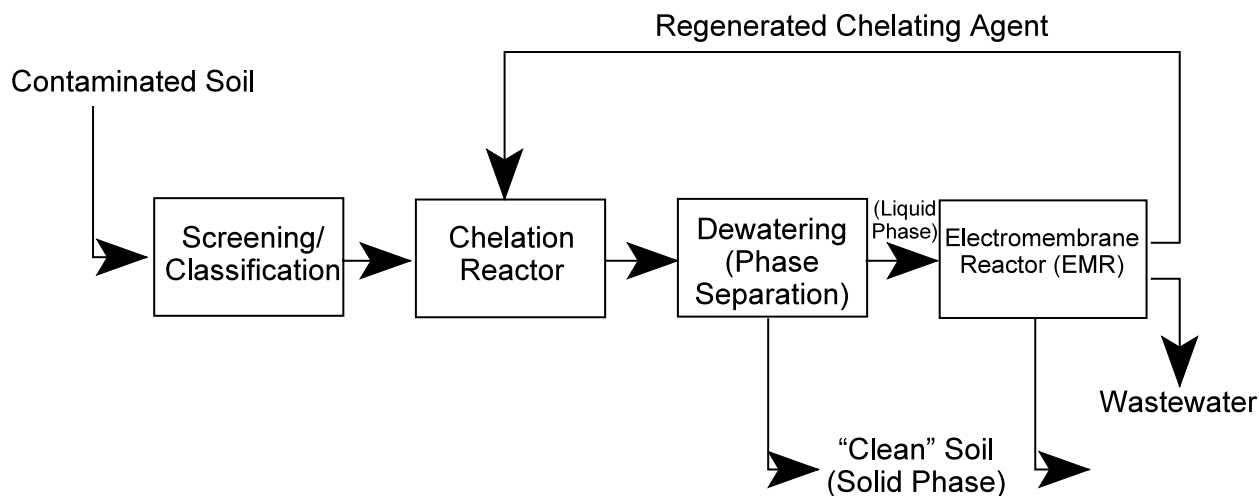
The treatment employs two key steps (see figure below): (1) a water-soluble chelating agent, such as ethylenediamine tetraacetic acid, bonds with heavy metals and forms a chelate; and (2) an electromembrane reactor (EMR) recovers the heavy metals from the chelate and regenerates the chelating agent.

Soils are screened before the chelation step to remove large particles such as wood, metal scrap, and large rocks.

The chelated soil is dewatered to separate the water-soluble chelating agent from the solid phase. The separated chelating agent, which contains heavy metals, is then treated in the EMR. The EMR consists of an electrolytic cell with a cation transfer membrane separating the cathode and anode chambers.

### WASTE APPLICABILITY:

The technology is applicable to a wide variety of metal-contaminated hazardous wastes, including soils and sludges. To date, IT Corporation has demonstrated the technology's effectiveness in removing lead and cadmium from soils and sludges.



Simplified Process Flow Diagram of Treatment Process

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in July 1994. The Jack's Creek site, located near Maitland, Pennsylvania, was selected as a site for technology evaluation. The site operated as a precious and nonprecious metal smelting and nonferrous metal recycling operation from 1958 to 1977. A portion of the property is currently operated as a scrap yard. Lead concentrations in the contaminated soil used for the evaluation was approximately 2 percent. Toxicity characteristic leaching procedure (TCLP) analysis on the contaminated soil showed lead levels of 7.7 milligrams per liter (mg/L), which exceeds the regulatory limit of 5 mg/L. During the project, IT Corporation established appropriate conditions for lead removal and recovery from the soil and reduced TCLP concentrations of lead in the soil to below regulatory levels.

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## IT CORPORATION (Mixed Waste Treatment Process)

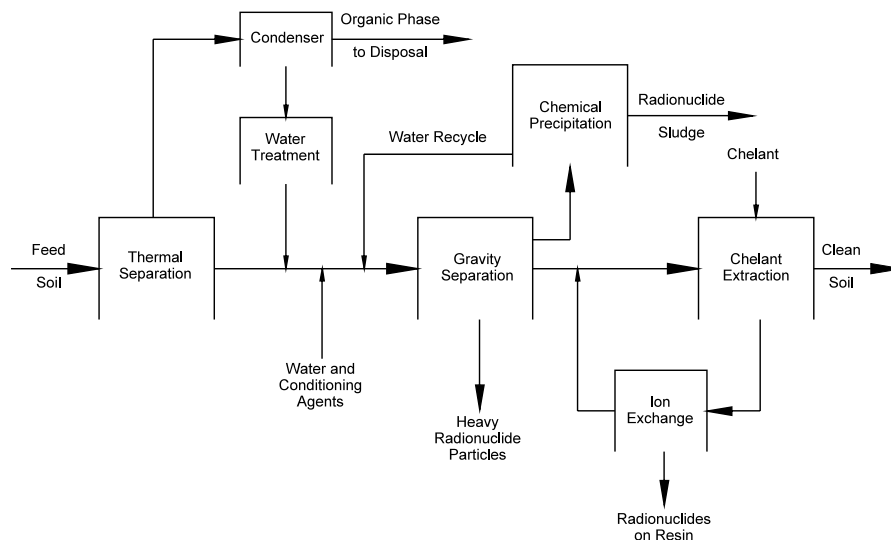
### TECHNOLOGY DESCRIPTION:

IT Corporation's mixed waste treatment process integrates thermal desorption, gravity separation, water treatment, and chelant extraction technologies to treat soils contaminated with hazardous and radioactive constituents. The process separates these contaminants into distinct organic and inorganic phases that can then be further minimized, recycled, or destroyed at commercial disposal facilities. The decontaminated soil can be returned to the site. Each technology has been individually demonstrated on selected contaminated materials. The process flow diagram below shows how the technologies have been integrated to treat mixed waste streams.

During the initial treatment step, feed soil is prepared using standard techniques, such as screening, crushing, and grinding to remove oversized material and provide a consistent feed material.

Thermal treatment removes volatile and semi-volatile organics from the soil. Soil is indirectly heated in a rotating chamber, volatilizing the organic contaminants and any moisture in the soil. The soil passes through the chamber and is collected as a dry solid. The volatilized organics and water are condensed into separate liquid phases. The organic phase is decanted and removed for disposal. The contaminated aqueous phase is passed through activated carbon, which removes soluble organics before combining with the thermally treated soil.

Inorganic contaminants are removed by three physical and chemical separation techniques: (1) gravity separation of high density particles; (2) chemical precipitation of soluble metals; and (3) chelant extraction of chemically bound metals.



Mixed Waste Treatment Process

Gravity separation is used to separate higher density particles from common soil. Radionuclide contaminants are typically found in this fraction. The gravity separation device (shaker table, jig, cone, or spiral) depends on contaminant distribution and the physical properties of the thermally treated soil.

Many radionuclides and other heavy metals are dissolved or suspended in the aqueous separation media. These contaminants are separated from the soils and are precipitated. A potassium ferrate formulation precipitates radionuclides. The resulting microcrystalline precipitant is removed, allowing the aqueous stream to be recycled.

Some insoluble radionuclides remain with the soil following the gravity separation process. These radionuclides are removed by chelant extraction. The chelant solution then passes through an ion-exchange resin to remove the radionuclides and is recycled to the chelant extraction step.

The contaminants are collected as concentrates from all waste process streams for recovery or off-site disposal at commercial hazardous waste or radiological waste facilities. The decontaminated soil can be returned to the site as clean fill.

## **WASTE APPLICABILITY:**

This process treats soils contaminated with organic, inorganic, and radioactive material.

## **STATUS:**

The mixed waste treatment process was selected for the SITE Emerging Technology Program in October 1991. Bench- and pilot-scale testing was completed in late 1995; a report detailing evaluation results was made available from EPA in 1997. Individual components of the treatment process have been demonstrated on various wastes from the U. S. Department of Energy, (DOE), the U.S. Department of Defense, and commercial sites. Thermal separation

has removed and recovered polychlorinated biphenyls from soils contaminated with uranium and technetium. These soils were obtained from two separate DOE gaseous diffusion plants.

Gravity separation of radionuclides has been demonstrated at pilot scale on Johnston Atoll in the Pacific. Gravity separation successfully removed plutonium from native coral soils.

Water treatment using the potassium ferrate formulations has been demonstrated at several DOE facilities in laboratory and full-scale tests. This treatment approach reduced cadmium, copper, lead, nickel, plutonium, silver, uranium, and zinc to dischargeable levels.

Chelant extraction has successfully treated surface contamination in the nuclear industry for more than 20 years. Similar results are expected for subsurface contamination.

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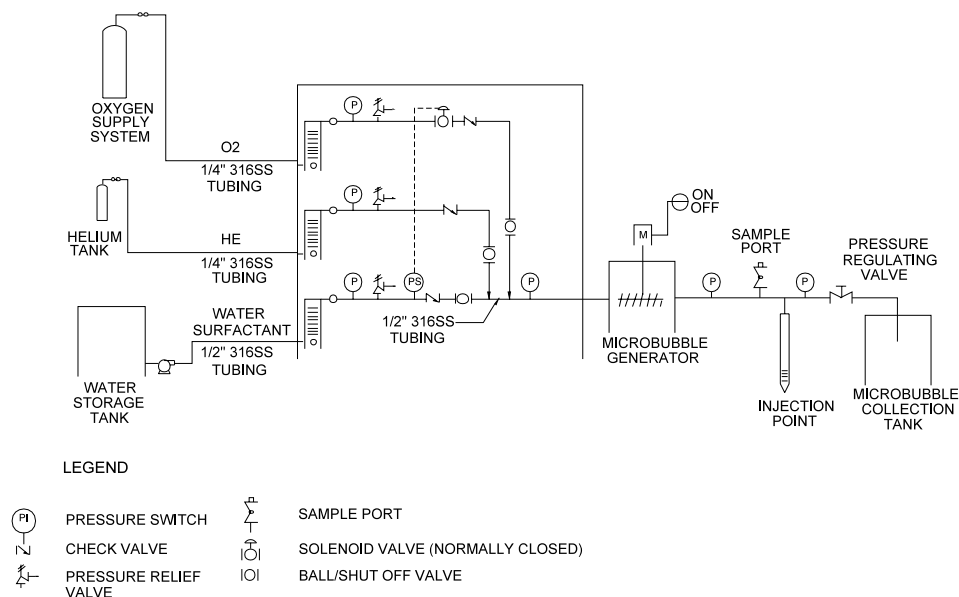
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**IT CORPORATION**  
**(formerly OHM Remediation Services Corporation)**  
**(Oxygen Microbubble In Situ Bioremediation)**

**TECHNOLOGY DESCRIPTION:**

The application of in situ microbial degradation of petroleum hydrocarbons (PHC) has become a common and widespread practice. The most common factor limiting the rate of in situ biodegradation of PHCs is the amount of oxygen available in the saturated and unsaturated zones. Therefore, OHM Remediation Services Corporation (OHM) has focused on developing techniques for delivering oxygen to the subsurface to enhance in situ microbial degradation of PHCs. OHM has extensive experience with oxygen delivery techniques such as bioventing and biosparging to enhance microbial degradation. Injection of oxygen microbubbles is being investigated by OHM as an oxygen delivery system for the in situ biodegradation of PHCs in the unsaturated and saturated zones. OHM has conducted laboratory tests and field demonstrations of the oxygen microbubble technology in conjunction with the U.S. EPA and the U.S. Armstrong Laboratories. Oxygen

microbubble technology (see figure below) uses a continuously generated stream of oxygen and water solution containing low concentrations of a surfactant. A water stream containing about 200 milligrams per liter of surfactant is mixed with oxygen under pressure. The resulting oxygen and water mixture is pumped through a microbubble generator that produces a zone of high-energy mixing. The result is a 60 to 80 percent by volume dispersion of bubbles, with a typical bubble diameter ranging from 50 to 100 microns. The microbubble dispersion is then pumped through an injection well into the treatment zone. The microbubbles deliver oxygen to contaminated groundwater, providing an oxygen source for aerobic biodegradation of the contaminant by the indigenous microflora.



Oxygen Microbubble In Situ Bioremediation

## WASTE APPLICABILITY:

The process has successfully treated groundwater contaminated with a number of organic compounds including volatile organic compounds, semivolatile organic compounds, and petroleum hydrocarbons.

## STATUS:

The Oxygen Microbubble In Situ Bioremediation process was accepted into the Emerging Technology Program in summer 1992. This process is being evaluated at a jet fuel spill site at Tyndall Air Force Base in Panama City, Florida.

The overall objective of this project is to evaluate the in situ application of the oxygen microbubble technology for bioremediation. The goals are to determine subsurface oxygen transfer to the groundwater, retention of the microbubble in the soil matrix, and biodegradation of the petroleum hydrocarbons present in the soil and groundwater.

A pilot test was performed at the site in 1995. The objective of the test was to determine the rate at which generated microbubbles could be injected into the surficial aquifer at the site. In addition, changes in the microbubbles and the aquifer during injection were monitored. Specific parameters monitored included the following:

- Microbubble quality, quantity, and stability
- Microbubble injection rate and pressure
- Lateral migration rates of microbubbles
- Lateral extent of migration of surfactant in the aquifer
- Lateral changes in dissolved oxygen concentration in the aquifer
- Rate of migration of tracer gas (helium) in the vadose zone
- Oxygen in the vadose zone

The pilot test verified that microbubbles can be injected into a shallow aquifer consisting of unconsolidated, fine-grained sediments. The study also verified that aquifer characteristics allowed the injection of the microbubble foam at rates of at least 1 gallon per minute. Continued injection of foam after about 45 minutes resulted in coalescence of the foam based on pressure measurements. The microbubble foam was observed to persist in the aquifer for long periods of time. This testing supported the use of oxygen microbubbles as an oxygen delivery system for in situ bioremediation.

The next testing phase at the site began in fall 1996. During this test, multiple injection points were used to determine the maximum rate of foam injection while maintaining foam stability. Oxygen was used as the gas for microbubble production. The retention of oxygen microbubbles was compared to sparged air to determine oxygen delivery efficiency.

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## IT CORPORATION (Photolytic and Biological Soil Detoxification)

### TECHNOLOGY DESCRIPTION:

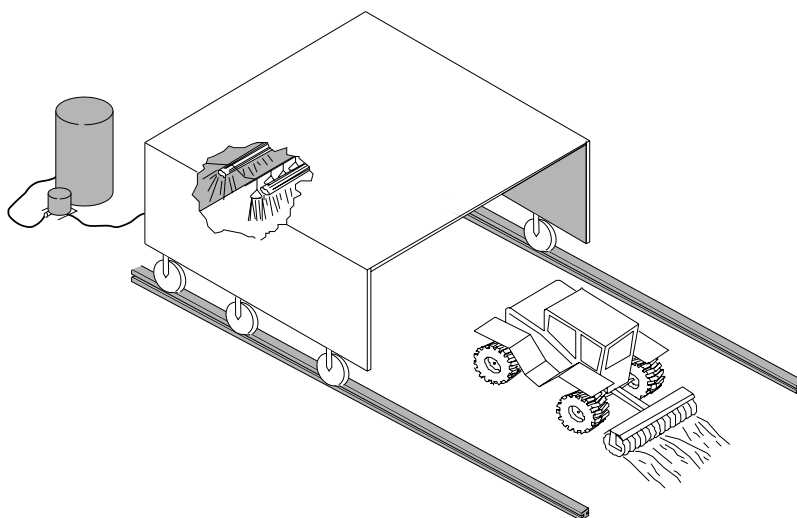
This technology is a two-stage, in situ photolytic and biological detoxification process for shallow soil contamination. The first step in the process degrades the organic contaminants with ultraviolet (UV) radiation. The photolytic degradation rate is several times faster with artificial UV light than with natural sunlight. The degradation process is enhanced by adding detergent-like chemicals (surfactants) to mobilize the contaminants. Photolysis of the contaminants converts them to more easily degraded compounds. Periodic sampling and analysis determines when photolysis is complete. Biodegradation, the second step, further destroys organic contaminants and detoxifies the soil.

When sunlight is used to treat shallow soil contamination, the soil is first tilled with a power tiller and sprayed with surfactant. The soil is tilled frequently to expose new surfaces and sprayed often. Water may also be added to maintain soil moisture.

When UV lights are used, parabolic reflectors suspended over the soil increase the amount of UV irradiation (see figure below). After photolysis is complete, biodegradation is enhanced by adding microorganisms and nutrients and further tilling the soil.

When these techniques are applied to soils with deep contamination, soil needs to be excavated and treated in a specially constructed shallow treatment basin that meets Resource Conservation and Recovery Act requirements. When soil contamination is shallow, photolysis and housing prevent contaminants from migrating to groundwater.

The only treatment residuals are soil contaminated with surfactants and the end metabolites of the biodegradation processes. The end metabolites depend on the original contaminants. The surfactants are common materials used in agricultural formulations. Therefore, the soils can be left on site.



Photolytic Degradation Process Using UV Lights

## WASTE APPLICABILITY:

This photolytic and biological soil detoxification process destroys organics, particularly dioxins such as tetrachlorodibenzo-p-dioxin (TCDD), polychlorinated biphenyls (PCB), other polychlorinated aromatics, and polynuclear aromatic hydrocarbons.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in 1989; the evaluation was completed in 1992. The Emerging Technology Report (PB95-159992) is available for purchase from the National Technical Information Services. The Emerging Technology Bulletin (EPA/540/F-94/502) and Emerging Technology Summary (EPA/540/SR-94/531) are available from EPA.

Bench-scale tests conducted on dioxin-contaminated soil showed that the effectiveness of surface irradiation to degrade TCDDs or PCBs is strongly influenced by soil type. Early tests on sandy soils showed greater than 90 percent removals for both TCDDs and PCBs. Using a 450-watt mercury lamp, the irradiation time was more than 20 hours for greater than 90 percent destruction of TCDD and more than 4 hours for greater than 90 percent destruction of PCBs. However, a high humic content decreased the effectiveness of the UV photolysis. Soil contaminated with PCBs in the bench-scale tests had a high clay content. The highest removal rate for these soils was 30 percent, measured over a 16-hour irradiation time.

The bench-scale tests used a medium-pressure mercury UV lamp; sunlight was ineffective. No significant improvement in PCB destruction was achieved using a pulsed UV lamp.

The process was also tested with Fenton's reagent chemistry as an alternate method of degrading PCBs to more easily biodegraded compounds. PCB destruction ranged from nondetectable to 35 percent. Data indicates that no significant change in PCB chlorine level distribution occurred during treatment.

Other studies examined PCB biodegradability in (1) soil treated with a surfactant and UV radiation, (2) untreated soil, and (3) soil known to have PCB-degrading organisms. Study results were as follows:

- PCB removal in the UV-treated soil, untreated soil, and soil with known biological activity was higher when augmented with an isolated PCB degrader (microorganism).
- In the untreated soil, biphenyl was more efficient at inducing PCB degradation than 4-bromobiphenyl.
- For the treated soil, surfactant treatment may have inhibited microbial activity due to high total organic carbon and low pH.

Isolation and enrichment techniques have made it possible to isolate microorganisms capable of biodegrading PCBs in contaminated soil.

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## IT CORPORATION (Tekno Associates Bioslurry Reactor)

### TECHNOLOGY DESCRIPTION:

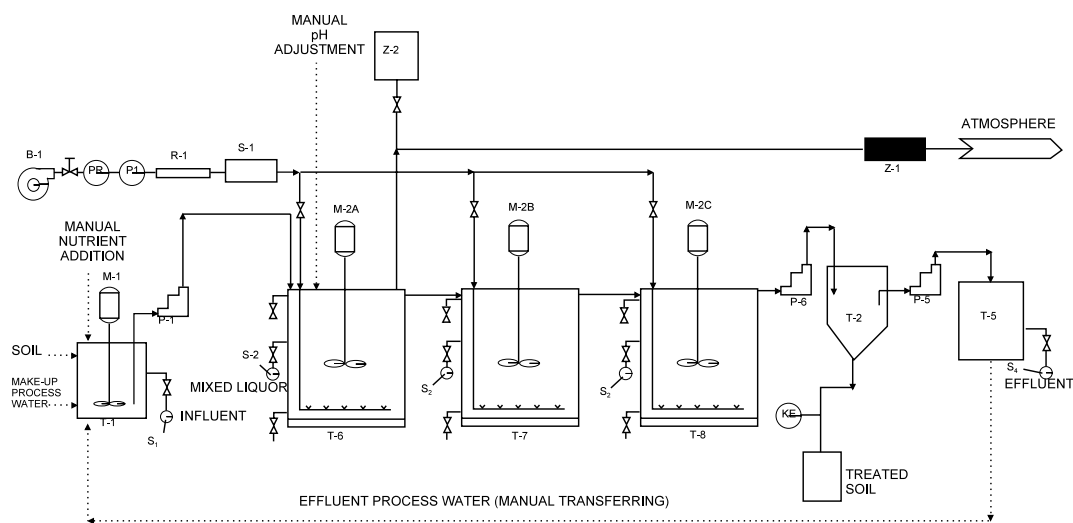
IT Corporation (IT) has used the Bioslurry Reactor (developed by Tekno Associates, Salt Lake City, Utah) to treat polynuclear aromatic hydrocarbons (PAH) in soil. Traditional biological treatments, such as landfarming and in situ bioremediation, may not reduce PAHs in soil to target levels in a timely manner. Slurry reactors are more efficient for bioremediation and more economical than thermal desorption and incineration.

During the project, IT operated one 10-liter and two 60-liter bioslurry reactors (see figure below) in semicontinuous, plug-flow mode. The first 60-liter reactor received fresh feed daily and supplements of salicylate and succinate. alicylate induces the naphthalene degradation operon on PAH plasmids in

the microorganisms. This system has been shown to degrade phenanthrene and anthracene. The naphthalene pathway may also play a role in carcinogenic PAH (CPAH) metabolism. Succinate is a by-product of naphthalene metabolism and serves as a general carbon source.

The first 60-liter reactor removed easily degradable carbon and increased biological activity against more recalcitrant PAHs (three-ring compounds and higher).

Effluent from the first reactor overflowed to the second 60-liter reactor in series, where Fenton's reagent (hydrogen peroxide and iron salts) was added to accelerate oxidation for four- to six-ring PAHs. Fenton's reagent produces a free radical that can oxidize multi-ring aromatic hydrocarbons.



#### LEGEND:

- (S<sub>1</sub>) SAMPLE PORT      (P<sub>1</sub>) PRESSURE REGULATOR  
 (P<sub>1</sub>) PRESSURE INDICATOR      (KE) TIMER

M-1 FEED MIXER	B-1 AIR BLOWER	R-1 AIR ROTAMETER	M-2ABC BIOREACTOR MIXER	T-7 BIOREACTOR 2 (SOIL)	Z-1 CARBON ADSORPTION	P-5 EFFLUENT PUMP	Z-2 AIR SAMPLING DEVICE
T-1 FEED CONTAINER (20L)	P-1 FEED PUMP (12 L/DAY)	S-1 AIR FILTER	T-6 BIOREACTOR 1 (SOIL)	T-8 BIOREACTOR 3 (SOIL)	P-6 SLURRY PUMP	T-2 CLARIFIER	T-5 EFFLUENT CONTAINER (20L)

### Tekno Associates Bioslurry Reactor System

The T-8 reactor (third in a series) was used as a polishing reactor to remove any partially oxidized contaminants remaining after the Fenton's reagent treatment. Slurry was removed from this reactor and clarified using gravity settling techniques.

Operation of the reactors as described increased the rate and extent of PAH biodegradation, making bioslurry treatment of impacted soils and sludges a more effective and economical remediation option.

### **WASTE APPLICABILITY:**

This technology is applicable to PAH-contaminated soils and sludges that can be readily excavated for slurry reactor treatment. Soils from coal gasification sites, wood-treating facilities, petrochemical facilities, and coke plants are typically contaminated with PAHs.

### **STATUS:**

This technology was accepted into the SITE Emerging Technology Program in 1993. Under this program, IT conducted a pilot-scale investigation of the three slurry reactors operating in series. A suitable soil for the pilot-scale test was obtained from a wood-treating facility in the southeastern U.S. About 4,000 pounds of PAH-impacted soil was screened and treated during summer 1994. CPAH and PAH removals were demonstrated at 84 and 95 percent, respectively. A final report is available from EPA.

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## **KSE, INC.**

### **(Adsorption-Integrated-Reaction Process)**

#### **TECHNOLOGY DESCRIPTION:**

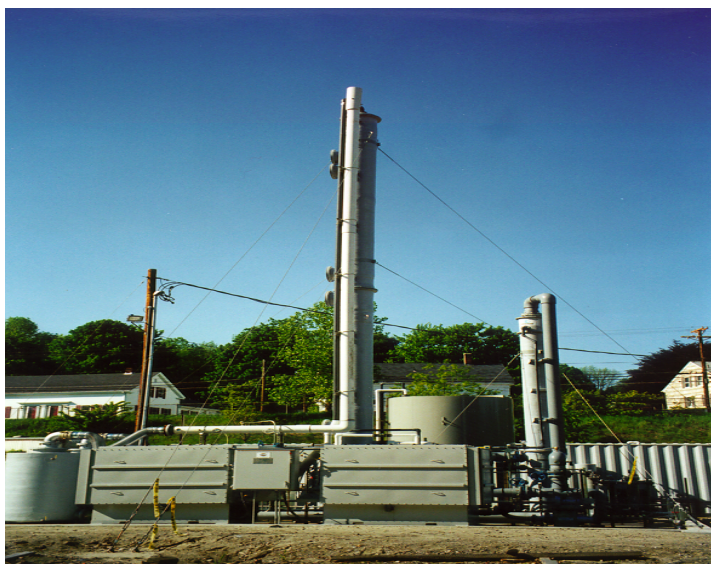
The Adsorption-Integrated-Reaction (AIR 2000) process combines two unit operations, adsorption and chemical reaction, to treat air streams containing dilute concentrations of volatile organic compounds (VOCs) (see photograph below).

The contaminated air stream containing dilute concentrations of VOCs flows into a photocatalytic reactor, where chlorinated and nonchlorinated VOCs are destroyed. The VOCs are trapped on the surface of a proprietary catalytic adsorbent. This catalytic adsorbent is continuously illuminated with ultraviolet light, destroying the trapped, concentrated VOCs through enhanced photocatalytic oxidation. This system design simultaneously destroys VOCs and continuously regenerates the catalytic adsorbent. Only oxygen in the air is needed as a reactant.

The treated effluent air contains carbon dioxide and water, which are carried out in the air stream exiting the reactor. For chlorinated VOCs, the chlorine atoms are converted to hydrogen chloride with some chlorine

gas. If needed, these gases can be removed from the air stream with conventional scrubbers and adsorbents. The AIR 2000 process offers advantages over other photocatalytic technologies because of the high activity, stability, and selectivity of the photocatalyst. The photocatalyst, which is not primarily titanium dioxide, contains a number of different semiconductors, which allows for rapid and economical treatment of VOCs in air. Previous results indicate that the photocatalyst is highly resistant to deactivation, even after thousands of hours of operation in the field.

The particulate-based photocatalyst allows for more freedom in reactor design and more economical scale-up than reactors with a catalyst film coated on a support medium. Packed beds, radial flow reactors, and monolithic reactors are all feasible reactor designs. Because the catalytic adsorbent is continuously regenerated, it does not require disposal or removal for regeneration, as traditional carbon adsorption typically does. The AIR 2000 process produces no residual wastes or by-products needing further treatment or disposal as hazardous waste. The treatment system is



AIR2000

self-contained and mobile, requires a small amount of space, and requires less energy than thermal incineration or catalytic oxidation. In addition, it has lower total system costs than these traditional technologies, and can be constructed of fiberglass reinforced plastic (FRP) due to the low operating temperatures.

## **WASTE APPLICABILITY:**

The AIR 2000 process is designed to treat a wide range of VOCs in air, ranging in concentration from less than 1 to as many as thousands of parts per million. The process can destroy the following VOCs: chlorinated hydrocarbons, aromatic and aliphatic hydrocarbons, alcohols, ethers, ketones, and aldehydes.

The AIR 2000 process can be integrated with existing technologies, such as thermal desorption, air stripping, or soil vapor extraction, to treat additional media, including soils, sludges, and groundwater.

The AIR 2000 process was accepted into the SITE Emerging Technology Program in 1995. Studies under the Emerging Technology Program are focusing on (1) developing photocatalysts for a broad range of chlorinated and nonchlorinated VOCs, and (2) designing advanced and cost-effective photocatalytic reactors for remediation and industrial service.

The AIR 2000 Process was initially evaluated at full-scale operation for treatment of soil vapor extraction off-gas at Loring Air Force Base (AFB). Destruction efficiency of tetrachloroethene exceeded 99.8 percent. The performance results were presented at the 1996 World Environmental Congress.

The AIR-I process, an earlier version of the technology, was demonstrated as part of a groundwater remediation demonstration project at Dover AFB in Dover, Delaware, treating effluent air from a groundwater stripper. Test results showed more than 99 percent removal of dichloroethane (DCA) from air initially containing about 1 ppm DCA and saturated with water vapor.

The AIR 2000 Process was accepted into the SITE Demonstration program in 1998. A demonstration was completed at a Superfund site in Rhode Island. A project bulletin was to be completed in 2001 and other project reports are still in preparation.

## **DEMONSTRATION RESULTS:**

A 700 SCFM commercial unit is now operating at a Superfund Site in Rhode Island, destroying TCE, DCE and vinyl chloride in the combined off-gas from a SVE system and a groundwater stripper. Results collected during August to October 1999 show that the system is operating at 99.6% destruction efficiency. The AIR 2000 unit is operating unattended, with the number of UV lamps being illuminated changing automatically in response to changing flow conditions for maximum performance at minimum cost.

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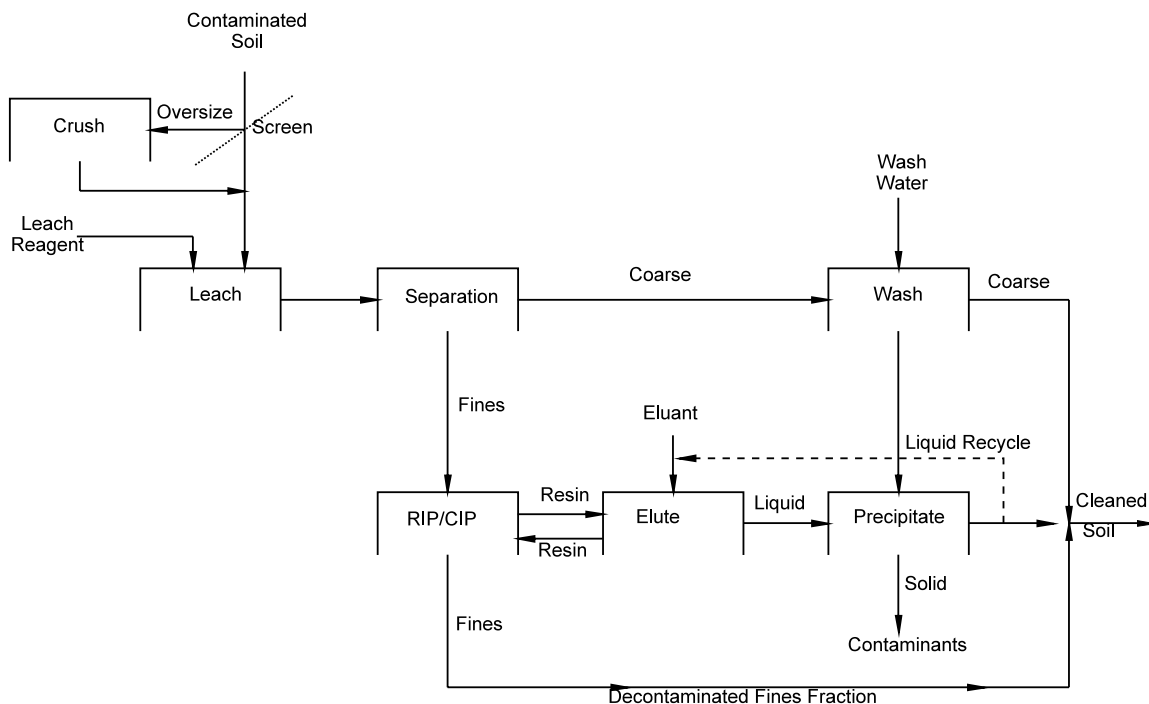
## KVAERNER ENERGY & ENVIRONMENT (formerly Davy International Environmental Division) (Chemical Treatment)

### TECHNOLOGY DESCRIPTION:

This treatment employs resin-in-pulp (RIP) or carbon-in-pulp (CIP) technologies to treat soils, sediments, dredgings, and solid residues contaminated with organic and inorganic material. These technologies are based on resin ion exchange and resin or carbon adsorption of contaminants from a leached soil-slurry mixture.

RIP and CIP processes are used on a commercial scale to recover metals from ores. The RIP process recovers uranium and uses anion exchange resins to adsorb uranium ions leached from ore. The CIP process recovers precious metals. In this process, activated carbon adsorbs gold and silver leached as cyanide

complexes. The figure below illustrates a typical process for metals and other inorganically contaminated soils. Incoming material is screened, and over-sized material is crushed. The two fractions are then combined and leached in an agitated tank, where the contaminants are extracted. The leached solids are then passed to cyclones that separate coarse and fine material. The coarse material is washed free of contaminants, and the wash liquors containing the contaminants are passed to the contaminant recovery section. The leached fine fraction passes to the RIP or CIP contactor, where ion-exchange resins or activated carbon remove the contaminants. The difficult fines washing step is thereby eliminated.



Chemical Treatment Process

The resins and carbons are eluted and recycled in the extraction step, and the concentrated contaminants in the effluent pass to the recovery section. In the recovery section, precipitation recovers contaminants from the wash and eluate solutions. The precipitation yields a concentrated solid material and can be disposed of or treated to recover metals or other materials. The liquid effluent from the recovery section can be recycled to the process.

For organically contaminated feeds, the in-pulp or slurry process treats the whole leached solid. Organic contaminants eluted from the resin or carbon must be treated appropriately by a separate technology.

Both the RIP and CIP commercial scale processes operate in multistage, continuous, countercurrent contactors arranged horizontally.

### **WASTE APPLICABILITY:**

This chemical treatment technology treats soils and other materials contaminated with inorganic and organic wastes. Inorganics include heavy metals such as copper, chromium, zinc, mercury, and arsenic. Treatment of materials containing organics such as chlorinated solvents, pesticides, and polychlorinated biphenyls requires appropriate extractant reagents and sorbent materials.

### **STATUS:**

This technology was accepted into the SITE Emerging Technology Program in July 1991. Laboratory studies have been underway since January 1991. Bench-scale tests have successfully met targets for removal of several heavy metal contaminants.

Arsenic and mercury have proven more difficult to remove; however, laboratory tests have reduced arsenic to below 30 milligrams per kilogram (mg/kg) in soil and mercury to 0.5 mg/kg in soil in the major fraction of the soil. Due to the lack of demand for this technology in the European Market, Davy has decided to withdraw from the SITE Program.

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## MATRIX PHOTOCATALYTIC INC. (Photocatalytic Air Treatment)

### TECHNOLOGY DESCRIPTION:

Matrix Photocatalytic Inc. is developing a titanium dioxide ( $\text{TiO}_2$ ) photocatalytic air treatment technology that destroys volatile organic compounds (VOC) and semivolatile organic compounds in air streams. During treatment, contaminated air at ambient temperatures flows through a fixed  $\text{TiO}_2$  catalyst bed activated by ultraviolet (UV) light. Typically, organic contaminants are destroyed in fractions of a second.

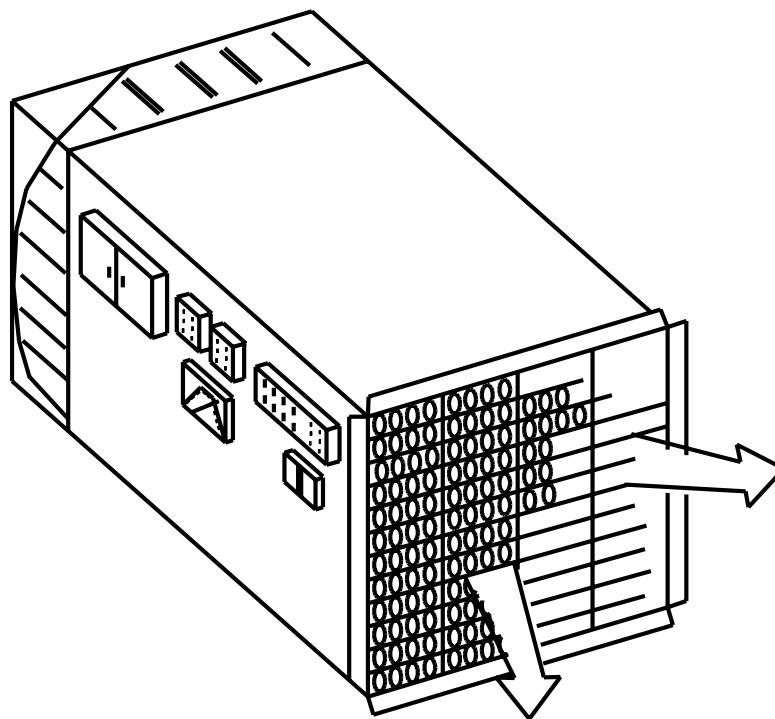
Technology advantages include the following:

- Robust equipment
- No residual toxins
- No ignition source
- Unattended operation
- Low direct treatment cost

The technology has been tested on benzene, toluene, ethylbenzene, and xylene; trichloroethene; tetrachloroethane; isopropyl alcohol; acetone; chloroform; methanol; and methyl ethyl ketone. A field-scale system is shown in the photograph on the next page.

### WASTE APPLICABILITY:

The  $\text{TiO}_2$  photocatalytic air treatment technology can effectively treat dry or moist air. The technology has been demonstrated to purify contaminant steam directly, thus eliminating the need to condense. Systems of 100 cubic feet per minute have been successfully tested on vapor extraction operations, air stripper emissions, steam from desorption processes, and VOC emissions from manufacturing facilities. Other potential applications include odor removal, stack gas treatment, soil venting, and manufacturing



Full-Scale Photocatalytic Air Treatment System

ultra-pure air for residential, automotive, instrument, and medical needs. Systems of up to about 1,000 cubic feet per minute can be cost- competitive with thermal destruction systems.

### **STATUS:**

The TiO<sub>2</sub> photocatalytic air treatment technology was accepted into SITE Emerging Technology Program (ETP) in October 1992; the evaluation was completed in 1993. Based on results from the ETP, this technology was invited to participate in the SITE Demonstration Program. For further information about the evaluation under the ETP, refer to the journal article (EPA/600/A-93/282), which is available from EPA. A suitable demonstration site is being sought.

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## **MATRIX PHOTOCATALYTIC INC.**

### **(Photocatalytic Aqueous Phase Organic Destruction)**

#### **TECHNOLOGY DESCRIPTION:**

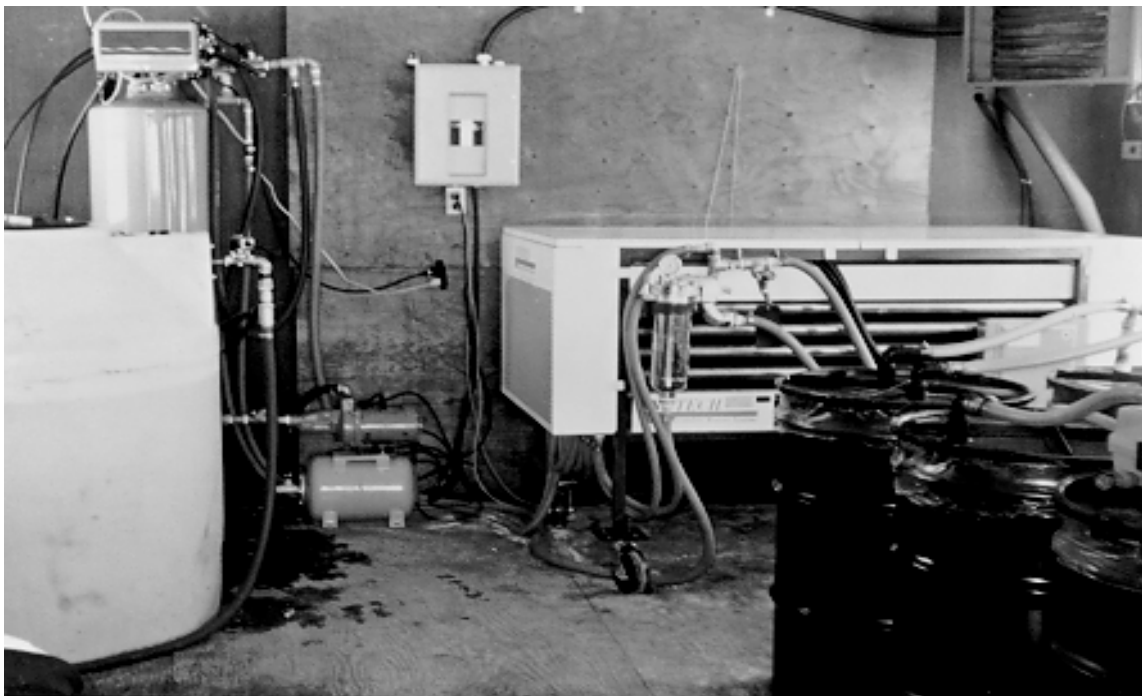
The Matrix Photocatalytic Inc. (Matrix) photocatalytic oxidation system, shown in the photograph below, removes dissolved organic contaminants from water and destroys them in a continuous flow process at ambient temperatures. When excited by light, the titanium dioxide ( $\text{TiO}_2$ ) semiconductor catalyst generates hydroxyl radicals that oxidatively break the carbon bonds of hazardous organic compounds.

The Matrix system converts organics such as polychlorinated biphenyls (PCB); phenols; benzene, toluene, ethylbenzene, and xylene (BTEX); and others to carbon dioxide, halides, and water. Efficient destruction typically occurs between 30 seconds and 2 minutes actual exposure time. Total organic carbon removal takes longer, depending on the other organic molecules and their molecular weights.

The Matrix system was initially designed to destroy organic pollutants or to remove total organic carbon from drinking water, groundwater, and plant process water. The Matrix system also destroys organic pollutants such as PCBs, polychlorinated dibenzodioxins, polychlorinated dibenzofurans, chlorinated alkenes, chlorinated phenols, chlorinated benzenes, alcohols, ketones, aldehydes, and amines. Inorganic pollutants such as cyanide, sulphite, and nitrite ions can be oxidized to cyanate ion, sulphate ion, and nitrate ion, respectively.

#### **WASTE APPLICABILITY:**

The Matrix system can treat a wide range of concentrations of organic pollutants in industrial wastewater and can be applied to the ultrapure water industry and the drinking water industry. The Matrix system can also remediate groundwater.



10-Gallon-Per-Minute  $\text{TiO}_2$  Photocatalytic System Treating BTEX in Water

## STATUS:

The system was accepted into the SITE Emerging Technology Program (ETP) in May 1991. Results from the ETP evaluation were published in a journal article (EPA/540/F-94/503) available from EPA. Based on results from the ETP, Matrix was invited to participate in the Demonstration Program.

During August and September 1995, the Matrix system was demonstrated at the K-25 site at the Department of Energy's Oak Ridge Reservation in Oak Ridge, Tennessee. Reports detailing the results from the demonstration are available from EPA.

## DEMONSTRATION RESULTS:

Results from the demonstration are detailed below:

- In general, high percent removals (up to 99.9 percent) were observed for both aromatic volatile organic compounds (VOCs) and unsaturated VOCs. However, the percent removals for saturated VOCs were low (between 21 and 40 percent).
- The percent removals for all VOCs increased with increasing number of path lengths and oxidant doses. At equivalent contact times, changing the flow rate did not appear to impact the treatment system performance for all aromatic VOCs and most unsaturated VOCs (except 1,1-dichloroethene [DCE]). Changing the flow rate appeared to impact the system performance for saturated VOCs.
- The effluent met the Safe Drinking Water Act maximum contaminant levels (MCL) for benzene; cis-1,2-DCE; and 1,1-DCE at a significant level of 0.05. However, the effluent did not meet the MCLs for tetrachloroethene (PCE); trichloroethene (TCE); 1,1-dichloroethane (DCA); and 1,1,1-trichloroethane (TCA) at a significant level of 0.05. The influent concentrations for toluene and total xylenes were below the MCLs.
- In tests performed to evaluate the effluent's acute toxicity to water fleas and fathead minnows, more than 50 percent of the organisms died. Treatment

by the Matrix system did not reduce the groundwater toxicity for the test organisms at a significant level of 0.05.

- In general, the percent removals were reproducible for aromatic and unsaturated VOCs when the Matrix system was operated under identical conditions. However, the percent removals were not reproducible for saturated VOCs. The Matrix system's performance was generally reproducible in (1) meeting the target effluent levels for benzene; cis-1,2-DCE; and 1,1-DCE; and (2) not meeting the target effluent levels for PCE; TCE; 1,1-DCA; and 1,1,1-TCA.
- Purgable organic compounds and total organic halides results indicated that some VOCs were mineralized in the Matrix system. However, formulation of aldehydes, haloacetic acids, and several tentatively identified compounds indicated that not all VOCs were completely mineralized.

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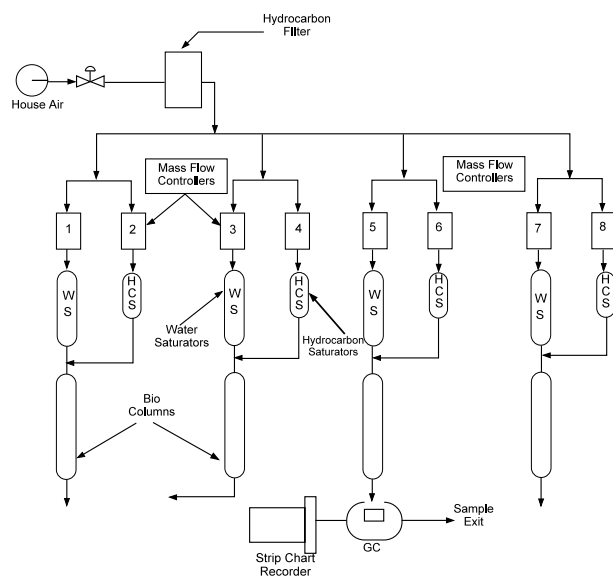
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## MEDIA & PROCESS TECHNOLOGY (formerly Aluminum Company of America and Alcoa Separation Technology, Inc.) (Bioscrubber)

This bioscrubber technology digests hazardous organic emissions generated by soil, water, and air decontamination processes. The bioscrubber consists of a filter with an activated carbon medium that supports microbial growth. This unique medium, with increased microbial population and enhanced bioactivity, converts diluted organics into carbon dioxide, water, and other nonhazardous compounds. The filter removes biomass, supplies nutrients, and adds moisture. A pilot-scale unit with a 4-cubic-foot-per-minute capacity is being field-tested (see figure below).

In addition to efficient degradation, the bioscrubber provides an effective sink to mitigate feed fluctuations. During an 11-month bench-scale test, the bioscrubber consistently removed contaminants such as petroleum hydrocarbons, alcohols, ketones, and amines from the waste feed at levels ranging from less than 5 to 40 parts per million (ppm).

The bioscrubber provides several advantages over conventional activated carbon adsorbers. First, bioregeneration keeps the maximum adsorption capacity constantly available; thus, the mass transfer zone remains stationary and relatively short. The carbon does not require refrigeration, and the required bed length is greatly reduced, thereby reducing capital and operating expenses. Finally, the chromatographic effect (premature desorption) common in an adsorber is eliminated because the maximum capacity is available constantly. The bioscrubber's advantages are fully exploited when the off-gas contains weakly adsorbed contaminants, such as methylene chloride, or adsorbates competing with moisture in the stream. The bioscrubber may replace activated carbon in some applications.



Bioscrubber Pilot-Scale Unit

## WASTE APPLICABILITY:

The bioscrubber technology removes organic contaminants in air streams from soil, water, or air decontamination processes. The technology is especially suited to treat streams containing aromatic solvents, such as benzene, toluene, and xylene, as well as alcohols, ketones, hydrocarbons, and others. The technology has several applications to Superfund sites, including (1) organic emission control for groundwater decontamination using air strippers, (2) emission control for biological treatment of ground and surface water, and (3) emission control for soil decontamination. These primary treatment processes have not been designed to prevent volatile organic compound discharges into the atmosphere. The bioscrubber is an ideal posttreatment component for these processes because it handles trace organic volatiles economically and effectively.

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in July 1990. Bench-scale bioscrubbers operated continuously for more than 11 months to treat an air stream with trace concentrations of toluene at about 10 to 20 ppm. The bioscrubbers accomplished a removal efficiency of greater than 95 percent. The filter had a biodegradation efficiency 40 to 80 times greater than existing filters. The project was completed in June 1993. Based on results from the Emerging Technology Program, the bioscrubber technology was invited to participate in the SITE Demonstration Program.

Evaluation results have been published in the report "Bioscrubber for Removing Hazardous Organic Emissions from Soil, Water and Air Decontamination Processes" (EPA/540/R-93/521). This report is

available from the National Technical Information Service. The Emerging Technology Bulletin (EPA/540/F-93/507) and the Emerging Technology Summary (EPA/540/SR-93/521) are available from EPA. An article on the technology was also published in the *Journal of Air and Waste Management*, Volume 44, March 1994, pp. 299-303.

The pilot-scale unit has also been tested on discharge from an air stripping tower at a flow rate of 2 standard cubic feet per minute. The discharge contained from less than 10 to 200 ppm toluene. The unit demonstrated the effectiveness, efficiency, and reliability of its design. Additional tests are underway to confirm results at higher flow rates and with other contaminants.

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## **MEMBRANE TECHNOLOGY AND RESEARCH, INC.** **(VaporSep® Membrane Process)**

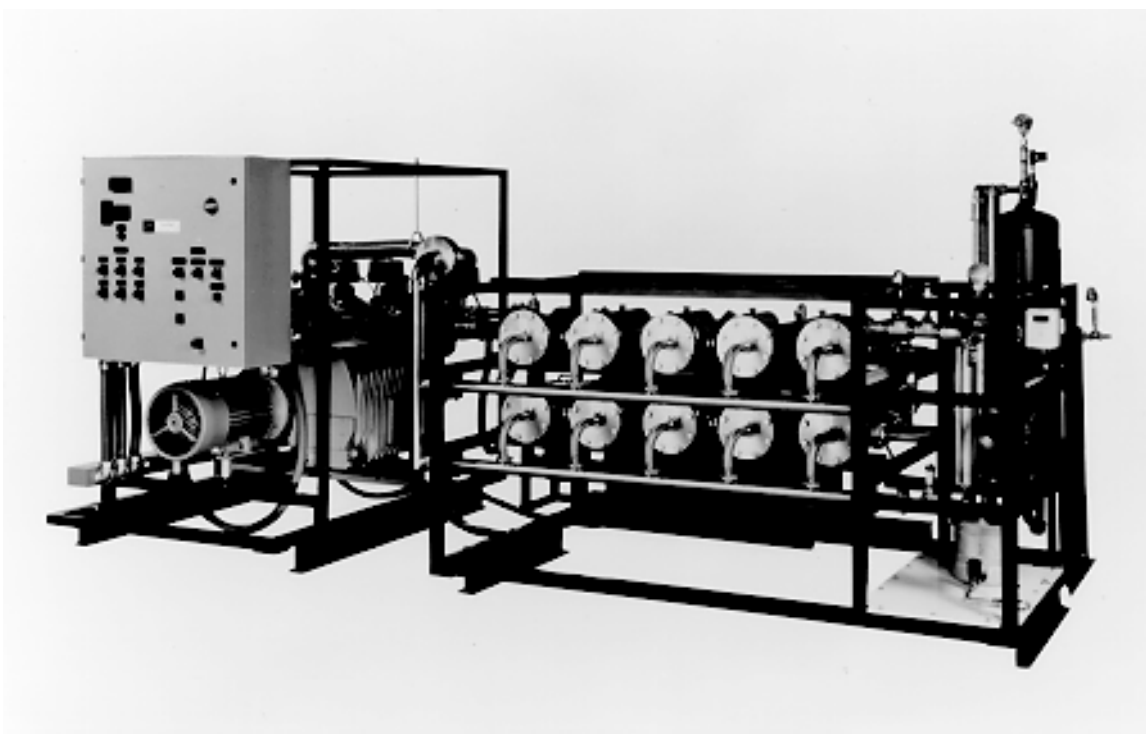
### **TECHNOLOGY DESCRIPTION:**

The Membrane Technology and Research, Inc., VaporSep® system, shown in the figure below, uses synthetic polymer membranes to remove organic vapors from contaminated air streams. The process generates a clean air stream and a liquid organic stream.

Air laden with organic vapor contacts one side of a membrane that is 10 to 100 times more permeable to the organic compound than to air. The membrane separates the air into two streams: a permeate stream containing most of the organic vapor, and a clean residual air stream. The organic vapor is condensed and removed as a liquid; the purified air stream may be vented or recycled.

The VaporSep® system maintains a lower vapor pressure on the permeate side of the membrane to drive the permeation process. This pressure difference can be created by either compressing the feed stream or using a vacuum pump on the permeate stream.

The VaporSep® systems built to date range in capacity from 1 to 700 standard cubic feet per minute. The systems are significantly smaller than carbon adsorption systems of similar capacity and can be configured for a wide range of feed flow rates and compositions. The process has been tested on air streams contaminated with a wide range of organic compounds at concentrations of 100 to over 100,000 parts per million.



VaporSep® Membrane Organic Vapor Recovery System

The VaporSep® system removes between 90 and 99 percent of the organic vapor, depending on the class of organic compound and the system design. The system produces only a purified air stream and a small volume of organic condensate. The concentration of organics in the purified air stream is generally low enough for discharge to the atmosphere.

## **WASTE APPLICABILITY:**

VaporSep® systems can treat most air streams containing flammable or nonflammable halogenated and nonhalogenated organic compounds, including chlorinated hydrocarbons, chlorofluorocarbons (CFC), and fuel hydrocarbons. Typical applications include the following:

- Reduction of process vent emissions, such as those regulated by EPA source performance standards for the synthetic organic chemical manufacturing industry.
- Treatment of air stripper exhaust before discharge to the atmosphere.
- Recovery of CFCs and hydrochlorofluorocarbons.
- Recovery of valuable organic feedstocks for recycling to the process.
- Recovery of gasoline vapors.

## **STATUS:**

This technology was accepted into the SITE Emerging Technology Program in 1989; the project was completed in 1991. The process, demonstrated at both the bench and pilot scales, achieved removal efficiencies of over 99.5 percent for selected organic compounds. The Emerging Technology Bulletin (EPA/540/ F-94/503) is available from EPA.

Almost 40 VaporSep® systems have been supplied to customers in the United States and overseas for applications such as the following:

- CFC and halocarbon recovery from process vents and transfer operations.
- CFC recovery from refrigeration systems.
- Vinyl chloride monomer recovery from polyvinyl chloride manufacturing operations.
- CFC-12/ethylene oxide recovery from sterilizer emissions.
- Recovery of monomers, other hydrocarbons, and nitrogen in polyolefin degassing processes.

A VaporSep® system successfully treated an air stream from a soil vacuum extraction operation at a U.S. Department of Energy site.

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**METSO MINERALS INDUSTRIES, INC.**  
**(formerly Svedala Industries, Inc.)**  
**(PYROKILN THERMAL ENCAPSULATION Process)**

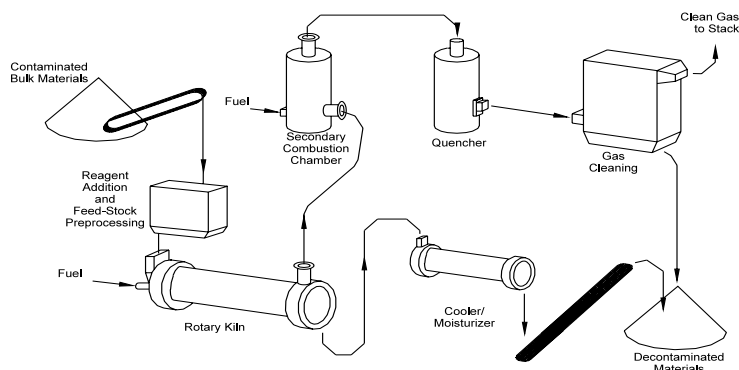
**TECHNOLOGY DESCRIPTION:**

The PYROKILN THERMAL ENCAPSULATION process is designed to improve conventional rotary kiln incineration of hazardous waste. The process introduces inorganic additives (fluxing agents) to the waste to promote incipient slagging or thermal encapsulating reactions near the kiln discharge. The thermal encapsulation is augmented using other additives in either the kiln or in the air pollution control (APC) baghouse to stabilize the metals in the fly ash. The process is designed to (1) immobilize the metals remaining in the kiln ash, (2) produce an easily handled nodular form of ash, and (3) stabilize metals in the fly ash, while avoiding the problems normally experienced with higher temperature "slagging kiln" operations.

The basis of this process is thermal encapsulation. Thermal encapsulation traps metals in a controlled melting process operating in the temperature range between slagging and nonslagging modes, producing ash nodules that are 0.25 to 0.75 inch in diameter.

The figure below illustrates the process. Wastes containing organic and metallic contaminants are incinerated in a rotary kiln. Metals (in particular, those with high melting points) are trapped in the bottom ash from the kiln through the use of fluxing agents that promote agglomeration with controlled nodulizing.

The PYROKILN THERMAL ENCAPSULATION process may reduce leaching of metals to levels below EPA Toxicity Characteristic Leaching Procedure (TCLP) limits for metals. Metals with low melting and vaporization temperatures, such as arsenic, lead, and zinc, are expected to partially volatilize, partitioning between the bottom ash and the fly ash. Metals concentrated in the fly ash may be stabilized, if necessary, by adding reagents to the kiln and to the APC system to reduce leaching to below TCLP limits. This process may also reduce the total dust load to the APC system and the amount of particulate emissions from the stack.



PYROKILN THERMAL ENCAPSULATION PROCESS

The use of fluxing reagents is a key element in this technology. The fluxing agents are introduced into the kiln in the proper amount and type to lower the ash's softening temperature. Proper kiln design is required to allow the kiln outlet to function as an ash agglomerator. Good temperature control is required to maintain the agglomerates at the correct particle size, yielding the desired 0.25- to 0.75-inch nodules. By producing nodules, rather than a molten slag, the process is expected to prevent operating problems such as ash quenching, overheating, and premature refractory failure. The process should also simplify cooling, handling, and conveyance of the ash.

The controlled nodulizing process should immobilize metals with high boiling points. Lead, zinc, and other metals with lower volatilization temperatures tend to exit the kiln as fine fumes. Reagents can be injected into the kiln, the APC devices, or a final solids mixer to aid in the collection of these metals from the gas stream.

### **WASTE APPLICABILITY:**

The technology is intended for soils and sludges contaminated with organics and metals. As with other rotary kiln systems, the process is expected to destroy a broad range of organic species, including halogenated and nonhalogenated organics and petroleum products. Svedala Industries, Inc., claims that the following metals may be encapsulated or stabilized: antimony, arsenic, barium, beryllium, cadmium, chromium, copper, lead, nickel, selenium, silver, thallium, and zinc.

### **STATUS:**

This technology was accepted into the SITE Emerging Technology Program in March 1990. A final report has been prepared, and a technical paper summarizing the project was presented in 1994 at the Air and Waste

Management Association 87th Annual Meeting and Exhibition in Cincinnati, Ohio. The final report was published in the July 1995 issue of the *Journal of the Air and Waste Management Association*.

A synthetic soil matrix was created for the batch rotary kiln tests. Feed preparation was a key element in nodule production. These tests yielded nodules with appropriate crush strength. Test results showed a decrease in TCLP metal leachate levels with increasing crush strength.

An analytical method involving microwave-aided digestion was used to evaluate samples produced in a second batch kiln test program. This method provided excellent, consistent results, indicating leachability below TCLP limits.

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## MONTANA COLLEGE OF MINERAL SCIENCE AND TECHNOLOGY (Air-Sparged Hydrocyclone)

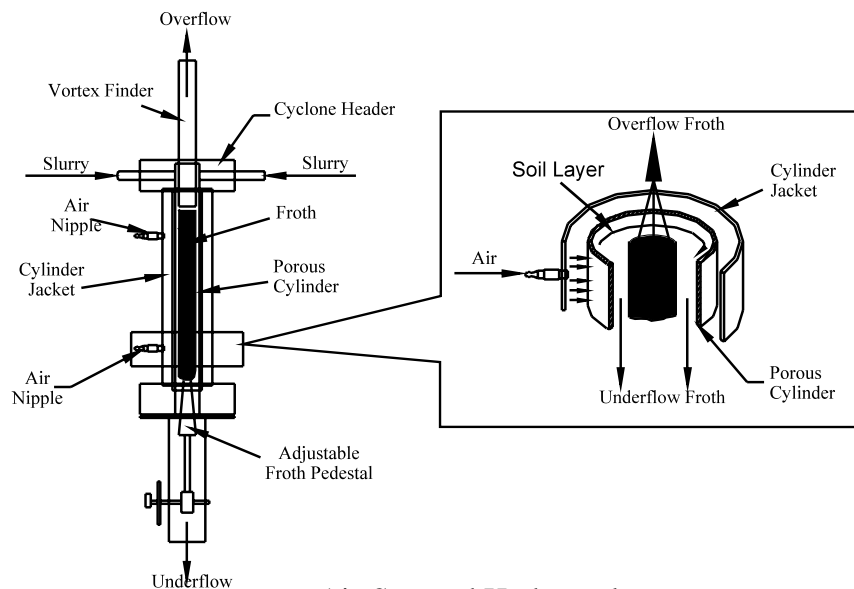
### TECHNOLOGY DESCRIPTION:

The air-sparged hydrocyclone (ASH) was developed at the University of Utah during the early 1980s to achieve fast flotation of fine particles in a centrifugal field. The ASH consists of two concentric right-vertical tubes with a conventional cyclone header at the top and a froth pedestal at the bottom (see figure below). The inner tube is a porous tube through which air is sparged. The outer tube serves as an air jacket to evenly distribute air through the porous inner tube.

Slurry is fed tangentially through the conventional cyclone header to develop a swirl flow of a certain thickness in the radial direction (the swirl-layer thickness). The swirl is discharged through an annular opening between the porous tube wall and the froth pedestal. Air is sparged through the porous inner tube wall and is sheared into small bubbles. These bubbles are then radially transported, together with attached

hydrophobic particles, into a froth phase that forms on the cyclone axis. The froth phase is stabilized and constrained by the froth pedestal at the underflow, moved toward the vortex finder of the cyclone header, and discharged as an overflow product. Water-wetted hydrophilic particles generally remain in the slurry phase and are discharged as an underflow product through the annulus created by the froth pedestal.

During the past decade, large mechanical flotation cells, such as aeration-stirred tank reactors, have been designed, installed, and operated for mineral processing. In addition, considerable effort has been made to develop column flotation technology in the United States and elsewhere; a number have been installed in industries. Nevertheless, for both mechanical and column cells, the specific flotation capacity is generally limited to 1 to 2 tons per day (tpd) per cubic foot of cell volume. In contrast, the ASH has a specific flotation capacity of at least 100 tpd per cubic foot of cell volume.



Air-Sparged Hydrocyclone

## **WASTE APPLICABILITY:**

Conventional flotation techniques used in industrial mineral processing are effective ways of concentrating materials. However, metal value recovery is never complete. The valuable material escaping the milling process is frequently concentrated in the very fine particle fraction.

The ASH can remove fine mineral particles that are not normally amenable to the conventional froth flotation process. These particles are generally sulfide minerals, such as galena (lead sulfide), sphalerite (zinc sulfide) and chalcopyrite (copper- iron-sulfide). Finely divided mining wastes containing these minerals oxidize and release the metallic elements as dissolved sulfates into the groundwater. Particularly applicable are tailings from older operations conducted before the development of froth flotation. Earlier operations recovered minerals by gravity concentration, which did not effectively capture fine particles and left tailings with relatively large concentrations of the environmentally hazardous fine sulfide minerals.

## **STATUS:**

This technology was accepted into the SITE Emerging Technology Program in June 1990. The most recent pilot plant trials on tailings generated by gravity concentration have confirmed both the technology's ability to recover sulfide minerals and the high throughput capacity claimed by proponents of the ASH. However, results on the economics of ash processing were inconclusive. Studies under the SITE Program were completed in August 1994, and a journal article is pending. The pilot plant was dismantled after 4 years of operation.

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## MONTANA COLLEGE OF MINERAL SCIENCE AND TECHNOLOGY (Campbell Centrifugal Jig)

### TECHNOLOGY DESCRIPTION:

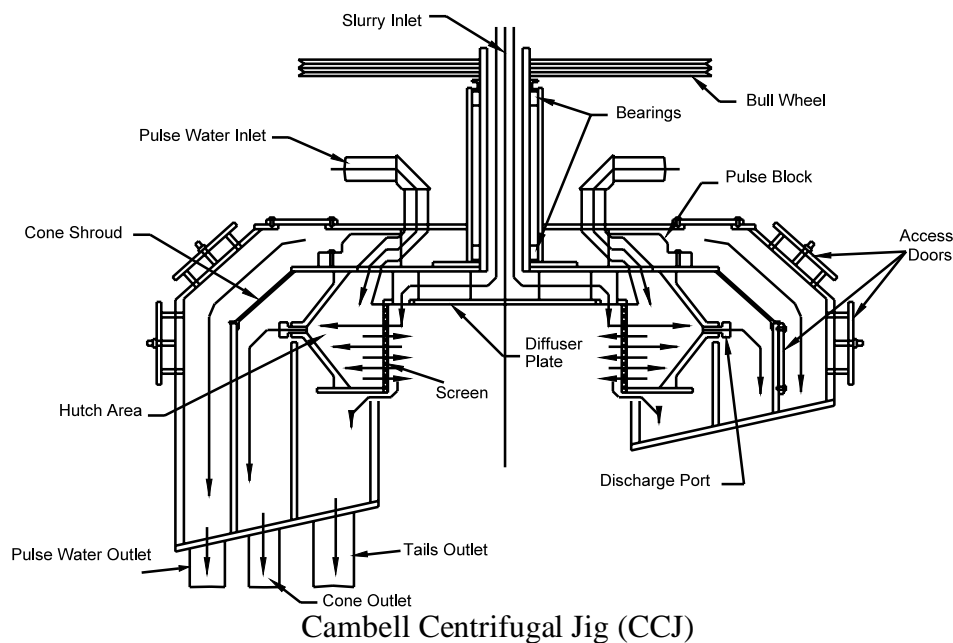
The Campbell Centrifugal Jig (CCJ) is a mechanical device that uses centrifugal force to separate fine heavy mineral and metal particles from waste materials. The CCJ combines jiggling and centrifuging to separate these particles from a fluid slurry. TransMar, Inc., owns the patents and rights to the CCJ technology.

Standard jigs separate solids of different specific gravities by differential settling in a pulsating bed and gravitational field. Jigs operating in this mode can recover solids larger than about 150 mesh (105 microns). Centrifuges are effective in separating solids from liquids but are not effective in separating solids from solids.

The CCJ, shown in the figure below, combines the continuous flow and pulsating bed of the standard jig with the enhanced acceleration forces of a centrifuge to segregate and concentrate heavy particles from the waste. The CCJ can recover particles ranging in size

from 1 to about 500 microns, depending on whether the particles are sufficiently disaggregated from the host material. The disaggregated particle should have a specific gravity at least 50 percent greater than the waste material. The CCJ does not need chemicals to separate the solids.

Appropriately sized, slurried material is fed into the CCJ through a hollow shaft inlet at the top of the machine. The slurried material discharges from the shaft onto a diffuser plate, which has vanes that distribute the material radially to the jig bed. The jig bed's surface is composed of stainless-steel shot raggings that is slightly coarser than the screen aperture. The jig bed is pulsated by pressurized water admitted through a screen by four rotating pulse blocks. The pulsing water intermittently fluidizes the bed, causing heavier particles to move through the raggings and screen to the concentrate port, while lighter particles continue across the face of the jig bed to the tailings port.



The effectiveness of separation depends on how well the original solids are disaggregated from the waste material and the specific gravity of each solid. The slurried feed material may require grinding to ensure

disaggregation of the heavy metals. Operating parameters include pulse pressure, rotation speed or g-load, screen aperture, ragging type and size, weir height, and feed percent solids.

The CCJ produces heavy mineral or metal concentrates which, depending on the waste material, may be further processed for extraction or sale. A clean tailings stream may be returned to the environment.

### **WASTE APPLICABILITY:**

The CCJ can separate and concentrate a wide variety of materials, ranging from base metals to fine coal ash and fine (1-micron) gold particles. Applications include (1) remediation of heavy metal-contaminated soils, tailings, or harbor areas containing spilled concentrates; (2) removal of pyritic sulfur and ash from fine coal; and (3) treatment of some sandblasting grit.

### **STATUS:**

The CCJ was accepted into the SITE Emerging Technology Program in May 1992. The CCJ was evaluated at the Montana College of Mineral Science and Technology Research Center (Montana Tech). Montana Tech equipped a pilot plant to evaluate the Series 12 CCJ, which has a capacity of 1 to 3 tons per hour. Tests were completed in August 1994 on base-metal mine tailings from various locations in western Montana. A report on these tests is pending.

In addition, under the U.S. Department of Energy (DOE) Integrated Demonstration Program, the CCJ was tested on clean Nevada test site soil spiked with bismuth as a surrogate for plutonium oxide. These tests occurred at the University of Nevada, Reno, during August and September 1994. In the future, the CCJ will be tested for its ability to remove radioactive contamination from soils from several DOE sites.

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## NEW JERSEY INSTITUTE OF TECHNOLOGY HAZARDOUS SUBSTANCES MANAGEMENT RESEARCH CENTER

(formerly Hazardous Substance Management  
Research Center at New Jersey  
Institute of Technology and  
Rutgers, the State University of New Jersey)  
(Pneumatic Fracturing and Bioremediation Process)

### TECHNOLOGY DESCRIPTION:

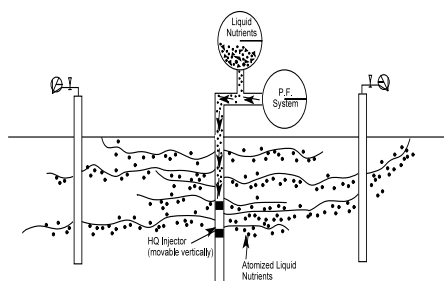
The Hazardous Substance Management Research Center (HSMRC) has developed a technology for the in situ remediation of organic contaminants. The process enhances in situ bioremediation through pneumatic fracturing to establish an extended biodegradation zone supporting aerobic, denitrifying, and methanogenic populations. The technique is designed to provide faster transport of nutrients and electron acceptors (for example, oxygen and nitrate) to the microorganisms, particularly in geologic formations with moderate to low permeability.

An overview of the process is shown in the figure below. First, the formation is pneumatically fractured by applying high pressure air in 2-foot-long, discrete intervals through a proprietary device known as an HQ Injector. After the formation has been fractured with air, nutrients or other chemicals are introduced into the fracture network to stimulate biological activity. The carrier gas and the particular amendments (atomized liquid or dry media) injected into the formation can be adjusted according to the target contaminant and the desired degradation environment (aerobic,

denitrifying, and anaerobic). The high air-to-liquid ratio atomizes the liquid supplements during injection, increasing their ability to penetrate the fractured formation. In the final step of the process, the site is operated as an in situ bioremediation cell to degrade the contaminants. A continuous, low-level air flow is maintained through the fracture network by a vacuum pump to provide oxygen to the microbial populations. Periodically, additional injections are made to replenish nutrients and electron acceptors.

### WASTE APPLICABILITY:

The integrated process can be applied to a wide variety of geologic formations. In geologic formations with low to moderate permeabilities, such as those containing clay, silt, or tight bedrock, the process creates artificial fractures which increase formation permeability. In formations with higher permeabilities, the process is still useful for rapid aeration and delivery of amendments to the microorganisms.



Overview of the Integrated Pneumatic Fracturing and Bioremediation Process

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in July 1991 and was evaluated at a gasoline refinery located in the Delaware Valley. The soil at the site was contaminated with benzene, toluene, and xylene (BTX) at concentrations up to 1,500 milligrams per kilogram, along with other hydrocarbons. The evaluation was completed in May 1994. Contact the EPA Project Manager for a copy of the results from the evaluation. A journal article has been submitted to the *Journal of Air and Waste Management*.

Throughout the 50-week pilot-scale, evaluation off-gases were monitored for BTX, carbon dioxide, and methane, which served as indicators of biological activity. Process effectiveness was evaluated through comparative analysis of soil samples collected at the beginning and the end of the evaluation.

Vapor extraction tests revealed postfracture air flows to be 24 to 105 times higher than prefracture air flows. Measurements of ground surface heave and observations of fractures venting to the ground surface indicated that the fractures had effective radii of up to 20 feet from the injection point.

Soil gas data collected at the monitoring wells show that the indigenous microbial populations responded favorably to the injection of the soil amendments. Soil gas data consistently showed elevated levels of carbon dioxide immediately following each injection, indicating increased rates of BTX mineralization. Correspondingly, BTX concentration levels in the wells gradually declined over time after depletion of oxygen and nitrate, at which time methanogenic processes began to dominate until the next subsurface amendment injection.

Comparative analysis of soil samples extracted from the site before and after the evaluation period showed that a substantial amount of BTX was degraded as a result of the integrated process. Total soil-phase BTX was reduced from 28 kilograms to 6 kilograms over the 50-week pilot test, corresponding to a 79 percent reduction in total BTX mass. An assessment of pathways of BTX loss from the formation showed a large proportion of the mass reduction (85 percent) was attributable to bioremediation.

Process development for this evaluation was supported in part by the U.S. Department of Defense, Advanced Research Projects Agency, and the Office of Naval Research.

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## NEW JERSEY INSTITUTE OF TECHNOLOGY (GHEA Associates Process)

### TECHNOLOGY DESCRIPTION:

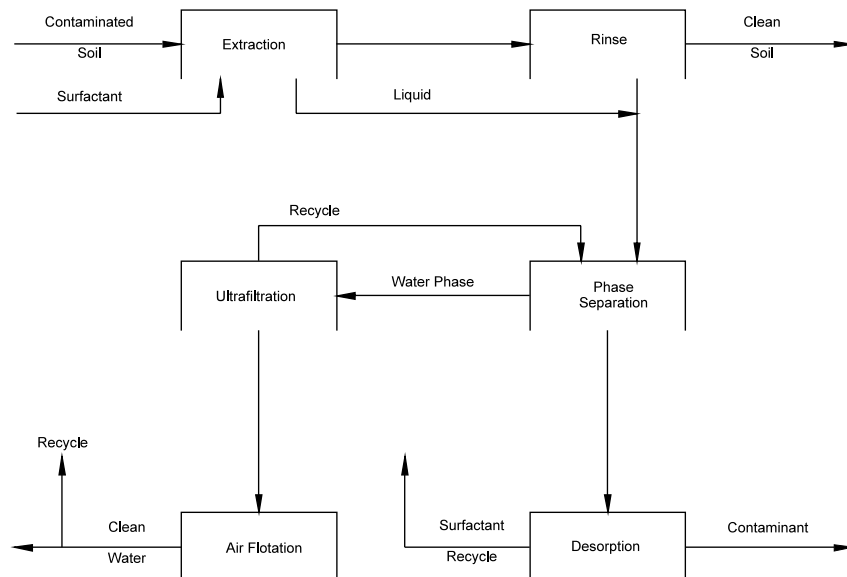
The GHEA Associates process applies surfactants and additives to soil washing and wastewater treatment to make organic and metal contaminants soluble. In soil washing, soil is first excavated, washed, and rinsed to produce clean soil. Wash and rinse liquids are then combined and treated to separate surfactants and contaminants from the water. Next, contaminants are separated from the surfactants by desorption and isolated as a concentrate. Desorption regenerates the surfactants for repeated use in the process.

The liquid treatment consists of a sequence of steps involving phase separation, ultrafiltration, and air flotation (see figure below). The treated water meets all National Pollutant Discharge Elimination System groundwater discharge criteria, allowing it to be (1) discharged without further treatment, and (2) reused in the process itself or reused as a source of high quality water for other users.

In wastewater treatment applications, surfactants added to the wastewater adsorb contaminants. The mixture is then treated in the same manner as described above for (1) water purification, (2) separation of the contaminants, and (3) recovery of the surfactants. The treatment process yields clean soil, clean water, and a highly concentrated fraction of contaminants. No other residues, effluents, or emissions are produced. The figure below illustrates the GHEA process.

### WASTE APPLICABILITY:

This technology can be applied to soil, sludges, sediments, slurries, groundwater, surface water, end-of-pipe industrial effluents, and in situ soil flushing. Contaminants that can be treated include both organics and heavy metals, nonvolatile and volatile organic compounds, and highly toxic refractory compounds.



GHEA Process for Soil Washing

## STATUS:

The technology was accepted into the SITE Emerging Technology Program in June 1990. Treatability tests were conducted on various matrices, including soils with high clay contents, industrial oily sludges, industrial wastewater effluents, and contaminated groundwater (see table below). In situ soil flushing tests have shown a 20-fold enhancement of contaminant removal rates. Tests using a 25-gallon pilot-scale plant have also been conducted. The Emerging Technology Bulletin (EPA/540/F-94/509), which details evaluation results, is available from EPA. Costs for treatment range from \$50 to \$80 per ton.

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SUMMARY OF TREATABILITY TEST RESULTS			
MATRIX	UNTREATED SAMPLE	TREATED SAMPLE	PERCENT REMOVAL
Volatile Organic Compounds (VOC): Trichloroethene; 1,2-Dichloroethene; Benzene; Toluene Soil, parts per million (ppm) Water, parts per billion (ppb)	20.13 109.0	0.05 2.5	99.7% 97.8%
Total Petroleum Hydrocarbons (TPH): Soil, ppm	13,600	80	99.4%
Polychlorinated Biphenyls (PCB): Soil, ppm Water, ppb	380.00 6,000.0	0.57 < 0.1	99.8% > 99.9%
Trinitrotoluene in Water, ppm	180.0	< .08	> 99.5%
Coal Tar Contaminated Soil (ppm): Benzo[a]pyrene Benzo[k]fluoranthene Chrysene Benzanthracene Pyrene Anthracene Phenanthrene Fluorene Dibenzofuran 1-Methylnaphthalene 2-Methylnaphthalene	28.8 24.1 48.6 37.6 124.2 83.6 207.8 92.7 58.3 88.3 147.3	< 0.1 4.4 < 0.1 < 0.1 < 0.1 < 0.1 < 0.1 < 0.1 < 0.1 1.3 < 0.1	> 99.7% 81.2% > 99.8% > 99.7% > 99.9% > 99.8% > 99.9% > 99.9% > 99.8% 98.5% > 99.9%
Heavy Metals In Soil: Chromium, ppm	21,000	640	96.8%
Iron (III) in Water, ppm:	30.8	0.3	99.0%



**PHARMACIA CORPORATION**  
(formerly Monsanto/DuPont)  
(Lasagna™ In Situ Soil Remediation)

**TECHNOLOGY DESCRIPTION:**

The Lasagna™ process, so named because of its treatment layers, combines electroosmosis with treatment layers which are installed directly into the contaminated soil to form an integrated, in-situ remedial process. The layers may be configured vertically or horizontally (see figures below). The process is designed to treat soil and groundwater contaminants completely in situ, without the use of injection or extraction wells.

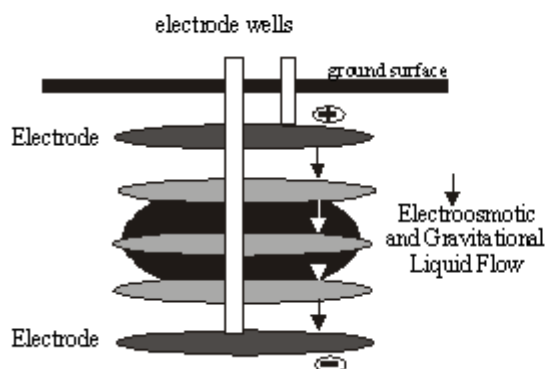
The outer layers consist of either positively or negatively charged electrodes which create an electrical potential field. The electrodes create an electric field which moves contaminants in soil pore fluids into or through treatment layers. In the vertical configuration, rods that are steel or granular graphite and iron filings can be used as electrodes. In the horizontal configuration, the electrodes and treatment zones are installed by hydraulic fracturing. Granular graphite is used for the electrodes and the treatment zones are granular iron (for zero-valent, metal-enhanced, reductive dechlorination) or granular activated carbon (for biodegradation by methanotropic microorganisms).

The orientation of the electrodes and treatment zones depends on the characteristics of the site and the contaminants. In general, the vertical configuration is probably more applicable to more shallow contamination, within 50 feet of the ground surface. The horizontal configuration, using hydraulic fracturing or related methods, is uniquely capable of treating much deeper contamination.

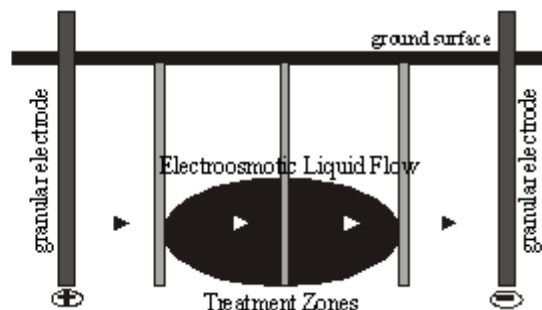
**WASTE APPLICABILITY:**

The process is designed for use in fine-grained soils (clays and silts) where water movement is slow and it is difficult to move contaminants to extraction wells. The process induces water movement to transport contaminants to the treatment zones so the contaminants must have a high solubility or miscibility in water. Solvents such as trichloroethylene and soluble metal salts can be treated successfully while low-solubility compounds such as polychlorinated biphenyls and polyaromatic hydrocarbons cannot.

A. Horizontal Configuration



B. Vertical Configuration



## STATUS:

The Lasagna<sup>TM</sup> process (vertical configuration) was accepted into the SITE Demonstration Program in 1995. Two patents covering the technology have been granted to Monsanto, and the term Lasagna<sup>TM</sup> has also been trademarked by Monsanto. Developing the technology so that it can be used with assurance for site remediation is the overall objective of the sponsoring consortium.

## DEMONSTRATION RESULTS:

The vertical configuration demonstration by Pharmacia at the Gaseous Diffusion Plant in Paducah, Kentucky, has been completed. The analysis of trends in TCE contamination of soil before and after Lasagna<sup>TM</sup> treatment indicated that substantial decreases did occur and the technology can be used to meet action levels.

The horizontal configuration demonstration by the University of Cincinnati and EPA at Rickenbacker ANGB (Columbus, OH) has been completed and both cells decommissioned. The cells were installed in soil containing TCE. The work demonstrated that horizontal Lasagna<sup>TM</sup> installations are feasible and that the installation results in some treatment of contaminants. The extent of treatment of the TCE-contaminated soil was not clear because of the small size of the cells and transport of TCE into the cells from adjacent contaminated areas.

In cooperation with the U.S. Air Force, EPA installed two horizontal configuration Lasagna<sup>TM</sup> cells in TCE-contaminated soil at Offutt AFB (Omaha, NE) in November 1998. The cells have been in operation since September 2000. An interim sampling in December 2000 at the four locations with highest concentrations in each cell showed slight decreases in organic chloride in one cell, but these were not statistically different from initial (pretreatment) concentrations. A second interim sampling will be conducted in June 2001 and the final (posttreatment) sampling in September 2001.

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## PHYTOKINETICS, INC. (Phytoremediation Process)

### TECHNOLOGY DESCRIPTION:

Phytoremediation is the treatment of contaminated soils, sediments, and groundwater with higher plants. Several biological mechanisms are involved in phytoremediation. The plant's ability to enhance bacterial and fungal degradative processes is important in the treatment of soils. Plant-root exudates, which contain nutrients, metabolites, and enzymes, contribute to the stimulation of microbial activity. In the zone of soil closely associated with the plant root (rhizosphere), expanded populations of metabolically active microbes can biodegrade organic soil contaminants.

The application of phytoremediation involves characterizing the site and determining the proper planting strategy to maximize the interception and degradation of organic contaminants. Site monitoring ensures that the planting strategy is proceeding as

planned. The following text discusses (1) using grasses to remediate surface soils contaminated with organic chemical wastes (Figure 1), and (2) planting dense rows of poplar trees to treat organic contaminants in the saturated groundwater zone (Figure 2).

Soil Remediation - Phytoremediation is best suited for surface soils contaminated with intermediate levels of organic contaminants. Preliminary soil phytotoxicity tests are conducted at a range of contaminant concentrations to select plants which are tolerant. The contaminants should be relatively nonleachable, and must be within the reach of plant roots. Greenhouse-scale treatability studies are often used to select appropriate plant species.

Grasses are frequently used because of their dense fibrous root systems. The selected species are planted, soil nutrients are added, and the plots are intensively cultivated. Plant shoots are cut during the growing



Phytoremediation of Surface Soil



Phytoremediation of the Saturated Zone

season to maintain vegetative, as opposed to reproductive, growth. Based on the types and concentrations of contaminants, several growing seasons may be required to meet the site's remedial goals.

Groundwater Remediation - The use of poplar trees for the treatment of groundwater relies in part on the tree's high rate of water use to create a hydraulic barrier. This technology requires the establishment of deep roots that use water from the saturated zone. Phytokinetics uses deep-rooted, water-loving trees such as poplars to intercept groundwater plumes and reduce contaminant levels. Poplars are often used because they are phreatophytic; that is, they have the ability to use water directly from the saturated zone.

A dense double or triple row of rapidly growing poplars is planted downgradient from the plume, perpendicular to the direction of groundwater flow. Special cultivation practices are used to induce deep root systems. The trees can create a zone of depression in the groundwater during the summer months because of their high rate of water use. Groundwater contaminants may tend to be stopped by the zone of depression, becoming adsorbed to soil particles in the aerobic rhizosphere of the trees. Reduced contaminant levels in the downgradient groundwater plume would result from the degradative processes described above.

### **WASTE APPLICABILITY:**

Phytoremediation is used for soils, sediments, and groundwater containing intermediate levels of organic contaminants.

### **STATUS:**

This technology was accepted into the SITE Demonstration Program in 1995. The demonstration will occur at the former Chevron Terminal #129-0350 site in Ogden, Utah. A total of 40 hybrid poplar trees were planted using a deep rooting technique in 1996 and data were collected through 1999 growing season.

### **DEMONSTRATION RESULTS:**

Water removal rates estimated using a water use multiplier and leaf area index to adjust a reference evapo-transpiration rate was 5 gallons per day per tree in 1998 and 113 gallons per day per tree in 1999. Water removal rates determined using SAP velocity measurements done in September and October of 1998 agreed closely with the estimated values. Although the trees transpired a volume of water equivalent to a 10-ft thickness of the saturated zone, water table elevation data collected in 1999 did not indicate a depression in the water table.

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## **PINTAIL SYSTEMS, INC.**

### **(Spent Ore Bioremediation Process)**

#### **TECHNOLOGY DESCRIPTION:**

This technology uses microbial detoxification of cyanide in heap leach processes to reduce cyanide levels in spent ore and process solutions. The biotreatment populations of natural soil bacteria are grown to elevated concentrations, which are applied to spent ore by drip or spray irrigation. Process solutions are treated with bacteria concentrates in continuous or batch applications. This method may also enhance metal remineralization, reducing acid rock drainage and enhancing precious metal recovery to offset treatment costs.

Biotreatment of cyanide in spent ore and ore processing solutions begins by identifying bacteria that will grow in the waste source and that use the cyanide for normal cell building reactions. Native isolates are ideally adapted to the spent ore environment, the available nutrient pool, and potential toxic components of the heap environment. The cyanide-detoxifying bacteria are typically a small fraction of the overall population of cyanide-tolerant species.

For this reason, native bacteria isolates are extracted from the ore and tested for cyanide detoxification potential as individual species. Any natural detoxification potentials demonstrated in flask cyanide decomposition tests are preserved and submitted for bioaugmentation. Bioaugmentation of the cyanide

detoxification population eliminates nonworking species of bacteria and enhances the natural detoxification potential by growth in waste infusions and chemically defined media. Pintail Systems, Inc. (PSI) maintains a bacterial library of some 2,500 strains of microorganisms and a database of their characteristics.

The working population of treatment bacteria is grown in spent ore infusion broths and process solutions to adapt to field operating conditions. The cyanide in the spent ore serves as the primary carbon or nitrogen source for bacteria nutrition. Other required trace nutrients are provided in the chemically defined broths. The bacterial consortium is then tested on spent ore in a 6-inch-by-10-foot column in the field or in the laboratory. The column simulates leach pile conditions, so that detoxification rates, process completion, and effluent quality can be verified. Following column tests, a field test may be conducted to verify column results.

The spent ore is remediated by first setting up a stage culturing system to establish working populations of cyanide-degrading bacteria at the mine site. Bacterial solutions are then applied directly to the heap using the same system originally designed to deliver cyanide solutions to the heap leach pads (see figure on previous page). Cyanide concentrations and leachable metals are then measured in heap leach solutions. This

method of cyanide degradation in spent ore leach pads degrades cyanide more quickly than methods which treat only rinse solutions from the pad. In addition to cyanide degradation, biological treatment of heap leach pads has also shown significant biomineralization and reduction of leachable metals in heap leachate solutions.

## **WASTE APPLICABILITY:**

The spent ore bioremediation process can be applied to treat cyanide contamination, spent ore heaps, waste rock dumps, mine tailings, and process water from gold and silver mining operations.

## **STATUS:**

This technology was accepted into the SITE Demonstration Program in May 1994. The field treatability study was conducted, at the Echo Bay/McCoy Cover mine site near Battle Mountain, Nevada, between June 11, 1997 and August 26, 1997.

## **DEMONSTRATION RESULTS:**

Results from the study are summarized below:

- The average % WAD CN reduction attributable to the Biocyanide process was 89.3 during the period from July 23 to August 26. The mean concentration of the feed over this period was 233 ppm, while the treated effluent from the bioreactors was 25 ppm. A control train, used to detect abiotic loss of cyanide, revealed no destruction of cyanide (average control effluent = 242 ppm).
- Metals that were monitored as part of this study were As, Cd, Co, Cu, Fe, Mn, Hg, Ni, Se, Ag, and Zn. Significant reductions were noted for all metals except Fe and Mn. Average reduction in metals concentration after July 23 for all other

metals were 92.7% for As, 91.6% for Cd, 61.6% for Co, 81.4% for Cu, 95.6% for Hg, 65.0% for Ni, 76.3% for Se, 94.6% for Ag, and 94.6% for Zn. Reductions for As, Cd, Co, and Se are probably greater than calculated due to non-detect levels in some effluent samples. A biomineralization mechanism is proposed for the removal of metals for solution. Biomineralization is a process in which microbes mediate biochemical reactions forming novel mineral assemblages on solid matrices.

- The Aqueous Biocyanide Process was operated for two and one-half months. During the first 42 days (June 11 to July 22) system performance was variable, and occasional downtimes were encountered. This was due to greatly higher cyanide and metals concentration in the feed than was encountered during benchscale and design phases of the project. Once optimized for the more concentrated feed, the system performed well with continuous operation for 35 days (July 23 to August 26). The ability to "re-engineer" the system in the field to accommodate the new waste stream is a positive attribute of the system.

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**PSI TECHNOLOGIES,  
A DIVISION OF PHYSICAL SCIENCES INC.  
(Metals Immobilization and Decontamination of Aggregate Solids)**

**TECHNOLOGY DESCRIPTION:**

PSI Technologies has developed a technology for metals immobilization and decontamination of aggregate solids (MeIDAS) (see figure below). The technology involves a modified incineration process in which high temperatures destroy organic contaminants in soil and concentrate metals into fly ash. The bulk of the soil ends up as bottom ash and is rendered nonleachable. The fly ash is then treated with a sorbent to immobilize the metals, as determined by the toxicity characteristic leaching procedure. The MeIDAS process requires a sorbent fraction of less than 5 percent by soil weight.

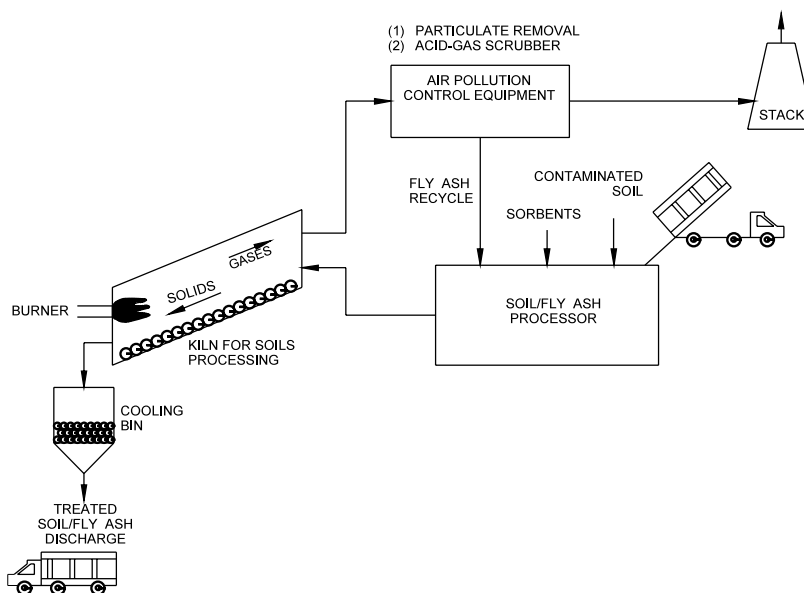
Standard air pollution control devices clean the effluent gas stream. Hydrogen chloride and sulfur dioxide, which may be formed from the oxidation of chlorinated organics and sulfur compounds in the waste, are cleaned by alkaline scrubbers. Fly ash is

captured by a particulate removal device, such as an electrostatic precipitator or baghouse. The only solid residues exiting the process are treated soils, which no longer contain organics and will not leach toxic metals.

**WASTE APPLICABILITY:**

The MeIDAS process treats organics and heavy metals in soils, sediments and sludges. The process has been effective in treating arsenic, cadmium, chromium, lead, nickel, and zinc.

The MeIDAS process is applicable to wastes contaminated with a combination of volatile metals and complex organic mixtures of low volatility. Possible MeIDAS process applications include battery waste sites and urban sites containing lead paint or leaded gasoline, or chemical or pesticide manufacturing facilities contaminated with organometallics.



MeIDAS Process

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in July 1991. Bench-scale testing under the SITE Program was completed in July 1992. The testing showed that organic, lead, and arsenic wastes could be successfully treated with less sorbent (1 to 10 percent of the soil by weight) than previously anticipated. Pilot-scale testing occurred in October 1992 and was completed in May 1993. The Emerging Technology Report has been submitted to EPA for review.

Initial testing, conducted under the EPA Small Business Innovative Research program, has demonstrated the feasibility of treating wastes containing arsenic, cadmium, lead, and zinc.

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## **PULSE SCIENCES, INC.**

### **(X-Ray Treatment of Aqueous Solutions)**

#### **TECHNOLOGY DESCRIPTION:**

X-ray treatment of organically contaminated aqueous solutions is based on the in-depth deposition of ionizing radiation. X-rays collide with matter, generating a shower of lower energy secondary electrons within the contaminated waste material. The secondary electrons ionize and excite the atomic electrons, break up the complex contaminant molecules, and form highly reactive radicals. These radicals react with the volatile organic compounds (VOC) and semivolatile organic compounds (SVOC) to form nontoxic by-products such as water, carbon dioxide, and oxygen.

An efficient, high-power, high-energy, linear induction accelerator (LIA) plus X-ray converter generates the X-rays used in the treatment process. The LIA energy, which must be small enough to avoid nuclear activation and as large as possible to increase the bremsstrahlung conversion efficiency, will most likely be in the range of 8 to 10 million electron volts (MeV). A repetitive pulse of electrons 50 to 100 nanoseconds long is directed onto a cooled converter of a high atomic number metal to efficiently generate X-rays. The X-rays then penetrate the container and treat the waste materials contained within.

Based on coupled electron/photon Monte Carlo transport code calculations, the effective penetration depth of X-rays produced by converting 10-MeV electrons is 32 centimeters in water after passing through the side of a standard 55-gallon drum. Large contaminant volumes can be easily treated without absorbing a significant fraction of the ionizing radiation in the container walls. Either flowing waste or contaminated waste in stationary or rotating containers can be treated. No additives are required for the process, and in situ treatment is feasible. The cost of high throughput X-ray processing is estimated to be competitive with alternative processes which decompose the contaminants.

#### **WASTE APPLICABILITY:**

X-ray processing can treat a large number of organic contaminants in aqueous solutions (groundwater, liquids, leachates, or wastewater) without expensive waste extraction or preparation. The technology has successfully treated 17 organic contaminants, listed in the table on the next page. No hazardous by-products are predicted to form or have been observed in the experiments.

#### **STATUS:**

This technology was accepted into the SITE Emerging Technology Program in May 1991 and was completed in April 1994. A 1.2-MeV, 800-ampere, 55-nanosecond LIA gave a dose rate of 5 to 10 rads per second. Twelve different VOCs and SVOCs found in Superfund sites were irradiated in 21 aqueous matrices prepared with a neat solution of the contaminant in reagent grade water. The amount of X-ray dose (1 rad =  $10^{-5}$  Joules per gram) required to decompose a particular contaminant was a function of its chemical bond structure and its reaction rate with the hydroxyl radical. When carbonate and bicarbonate ions (hydroxyl radical scavengers) were present in contaminated well water samples, approximately five times the X-ray dose was required to decompose contaminants that react strongly with the hydroxyl radical. The remediation rate of carbon tetrachloride, which does not react with hydroxyl radicals, was not affected.

An X-ray dose of 150 kilorads (krad) reduced the moderate contamination levels in a well water sample from a Superfund site at Lawrence Livermore National Laboratory (LLNL) to less than those set by the California Primary Drinking Water Standards. For a more highly contaminated LLNL well water sample, experimental data suggested a 500-krad dose was needed to reduce the contamination levels to drinking water standards.

In principle, the rate coefficients determined from the data can be used to estimate the dose level required to destroy mixtures of multiple VOC contaminants and OH- radical scavengers. However, these estimates should be applied judiciously. Only the experimentally determined destruction curves, based on the remediation of test samples of the actual mixture, can be used with confidence at the present. The table below summarizes the X-ray treatment results from the SITE evaluation.

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CONTAMINANT	MATRIX	INITIAL CONCENTRATION (ppb)*	FINAL CONCENTRATION (ppb)	CPDWS** (ppb)	X-RAY DOSE (krad)
TCE	Deionized Water	9,780	< 0.1	5	50.3
PCE		10,500	< 0.1	5	69.8
Chloroform		2,000	4.4	--	178
Methylene Chloride		270	3.1	5	145.9
Trans-1,2-Dichloroethene		260	0.78	10	10.6
Cis-1,2-Dichloroethene		13	< 0.5	6	10.6
1,1,1-Trichloroethane		590	54	200	207.1
Carbon Tetrachloride (CCl <sub>4</sub> )		180	14	0.5	224
Benzene		240	< 0.5	1	8.8
Toluene		150	< 0.5	150	4.83
Ethylbenzene		890	3.6	680	20.4
Xylene		240	1.2	1,750	5.6
Benzene/CCl <sub>4</sub>	Contaminated Well Water	262/400	< 0.5/196	1/0.5	39.9/93.8
Ethylbenzene/CCl <sub>4</sub>		1,000/430	< 0.5/70.9	680/0.5	33.2/185
Ortho-xylene/CCl <sub>4</sub>		221/430	< 0.5/85	1,750/0.5	20.5/171
TCE	LLNL Well Water Sample #1	3,400	< 0.5	5	99.0
PCE		500	< 0.5	5	99.0
1,1-Dichloroethane		< 10	1	5	145.4
1,1-Dichloroethene		25	< 1	6	49.9
1,1,1-Trichloroethane		13	2.0	200	145.4
Cis-1,2-Dichloroethene		14	< 0.5	6	49.9
TCE	LLNL Well Water Sample #2	5,000	< 1.0	5	291
PCE		490	1.6	5	291
Chloroform		250	81	--	291
CCl <sub>4</sub>		14	4	0.5	291
1,2-Dichloroethane		38	17	5	291
1,1-Dichloroethane		11	6.8	5	291
Freon		71	32	--	291

\* parts per billion  
\*\* California Primary Drinking Water Standards

## Summary of X-ray Treatment Results

## PULSE SCIENCES, INC. (X-Ray Treatment of Organically Contaminated Soils)

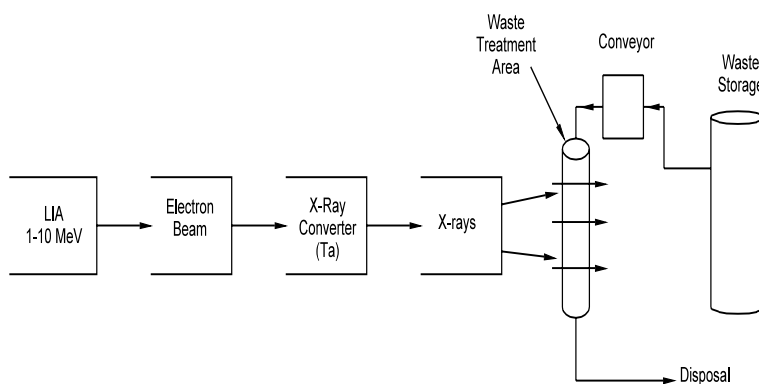
### TECHNOLOGY DESCRIPTION:

X-ray treatment of organically contaminated soils is based on in-depth deposition of ionizing radiation. Energetic photons (X-rays) collide with matter to generate a shower of lower-energy, secondary electrons within the contaminated waste material. These secondary electrons ionize and excite the atomic electrons, break up the complex contaminant molecules, and form highly reactive radicals. These radicals react with contaminants to form nonhazardous products such as water, carbon dioxide, and oxygen.

Other sources of ionizing radiation, such as ultraviolet radiation or direct electron beam processing, do not penetrate the treatable material deeply enough. Ultraviolet radiation heats only the surface layer, while a 1.5-million electron volt (MeV) charge penetrates about 4 millimeters into the soil. X-rays, however, penetrate up to 20 centimeters, allowing treatment of thicker samples. In situ treatment, which reduces material handling requirements, may also be possible with X-ray treatment.

An efficient, high-power, high-energy, linear induction accelerator (LIA) plus X-ray converter generates the X-rays used in the treatment process (see figure below). The LIA energy usually ranges from 8 to 10 MeV. A repetitive pulse of electrons 50 to 100 nanoseconds long is directed onto a cooled converter of high atomic number to efficiently generate X-rays. The X-rays penetrate and treat the organically contaminated soils.

The physical mechanism by which volatile organic compounds (VOC) and semivolatile organic compounds (SVOC) are removed primarily depends on the specific contaminant present. Because of the moisture in contaminated soil, sludge, and sediments, the shower of secondary electrons resulting from X-ray deposition produces both highly oxidizing hydroxyl radicals and highly reducing aqueous electrons. While hazardous by-products may form during X-ray treatment, contaminants and by-products, if found, may be completely converted at sufficiently high dose levels without undesirable waste residuals or air pollution.



X-Ray Treatment Process

X-rays can treat contaminated soil on a conveyor or contained in disposal barrels. Because X-rays penetrate about 20 centimeters into soil, large soil volumes can be treated without losing a significant fraction of the ionizing radiation in standard container walls. Pulse Sciences, Inc., estimates that the cost of high throughput X-ray processing is competitive with alternative processes that decompose the contaminants.

### **WASTE APPLICABILITY:**

X-ray treatment of organically contaminated soils has the potential to treat large numbers of contaminants with minimum waste handling or preparation. Also, X-ray treatment can be applied in situ. In situ treatment may be of significant importance in cases where it is impossible or impractical to reconfigure the waste volume for the ionizing radiation range of electrons or ultraviolet radiation. Treatable organic contaminants include benzene, toluene, xylene, trichloroethene, tetrachloroethene, carbon tetrachloride, chloroform, and polychlorinated biphenyls.

### **STATUS:**

This technology was accepted into the SITE Emerging Technology Program in 1993. A 1.2-MeV, 800-ampere (amp), 50-watt LIA and a 10.8-MeV, 0.2-amp, 10,000-watt radio frequency (RF) linac will be used in the program. The primary objectives are to (1) demonstrate that X-ray treatment can reduce VOC and SVOC levels in soils to acceptable levels, and (2) determine any hazardous by-product that may be produced.

Samples with identical initial contaminant concentration levels will be irradiated at increasing dose levels to determine (1) the rate (concentration versus dose) at which the contaminants are being destroyed, and (2) the X-ray dose required to reduce organic contamination to acceptable levels. The 10.8-MeV RF linac, which produces more penetrating X-rays, should provide information on the optimum X-ray energy for the treatment process. Increasing the accelerator energy allows a more efficient conversion from electrons to X-rays in the converter, but an upper limit (about 10 MeV) restricts the energy treatment, because higher energy activates the soil. The experimental database will be used to develop a conceptual design and cost estimate for a high throughput X-ray treatment system.

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**RECRA ENVIRONMENTAL, INC.**  
**(formerly Electro-Pure Systems, Inc.)**  
**(Alternating Current Electrocoagulation Technology)**

**TECHNOLOGY DESCRIPTION:**

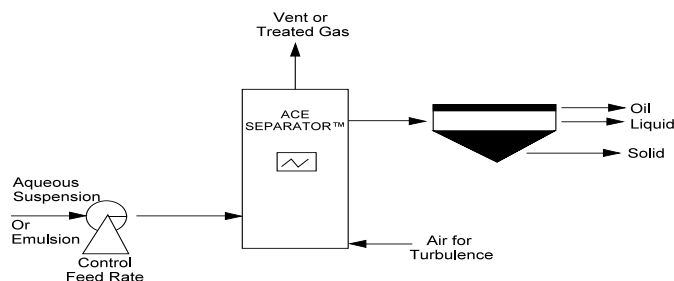
The alternating current electrocoagulation (ACE) technology offers an alternative to the use of metal salts or polymers and polyelectrolyte addition for breaking stable emulsions and suspensions. The technology removes metals, colloidal solids and particles, and soluble inorganic pollutants from aqueous media by introducing highly charged polymeric aluminum hydroxide species. These species neutralize the electrostatic charges on suspended solids and oil droplets to facilitate agglomeration or coagulation and resultant separation from the aqueous phase. The treatment prompts the precipitation of certain metals and salts.

The figure below depicts the basic ACE process. Electrocoagulation occurs in either batch mode, allowing recirculation, or continuous (one-pass) mode in an ACE fluidized bed separator. Electrocoagulation is conducted by passing the aqueous medium through the treatment cells in upflow mode. The electrocoagulation cell(s) consist of nonconductive piping equipped with rectilinearly shaped, nonconsumable metal electrodes between which is maintained a turbulent, fluidized bed of aluminum alloy pellets.

Application of the alternating current electrical charge to the electrodes prompts the dissolution of the fluidized bed and the formation of the polymeric hydroxide species. Charge neutralization is initiated within the electrocoagulation cell(s) and continues following effluent discharge. Application of the electrical field prompts electrolysis of the water medium and generates minute quantities of hydrogen gas. The coagulated solids will often become entrained in the gas, causing their flotation.

Attrition scrubbing of the fluidized bed pellets within the cell inhibits the buildup of scale or coating on the aluminum pellets and the face of the electrodes. Coagulation and flocculation occur simultaneously within the ACE cells as the effluent is exposed to the electric field and the aluminum dissolves from the fluidized bed.

The working volume of the fluidized bed cell, excluding external plumbing, is 5 liters. The ACE systems have few moving parts and can easily be integrated into a process treatment train for effluent, pretreatment, or polishing treatment. The ACE technology has been designed into water treatment systems which include membrane separation, reverse osmosis, electrofiltration, sludge dewatering, and thermo-oxidation technologies.



Alternating Current Electrocoagulation (ACE)

System operating conditions depend on the chemistry of the aqueous medium, particularly the conductivity and chloride concentration. Treatment generally requires application of low voltage (<135 VAC) and operating currents of less than 20 amperes. The flow rate of the aqueous medium through the treatment cell(s) depends on the solution chemistry, the nature of the entrained suspension or emulsion, and the treatment objectives.

Product separation occurs in conventional gravity separation devices or filtering systems. Each phase is removed for reuse, recycling, additional treatment, or disposal.

Current systems are designed to treat waste streams of between 10 and 100 gallons per minute (gpm). RECRA Environmental, Inc., maintains a bench-scale unit (1 to 3 gpm) at its Amherst Laboratory for use in conducting treatability testing.

## WASTE APPLICABILITY:

The ACE technology treats aqueous-based suspensions and emulsions such as contaminated groundwater, surface water runoff, landfill and industrial leachate, wash and rinse waters, and various solutions and effluents. The suspensions can include solids such as inorganic and organic pigments, clays, metallic powders, metal ores, and colloidal materials. Treatable emulsions include a variety of solid and liquid contaminants, including petroleum-based by-products.

The ACE technology has demonstrated reductions of clay, latex, and various hydroxide loadings by over 90 percent. Chemical oxygen demand and total organic carbon content of spiked slurries have been reduced by over 80 percent. The technology has removed heavy metals at between 55 and 99 percent efficiency. Fluoride and phosphate have been removed at greater than 95 percent efficiency. The system has been used to recover fine-grained products which would otherwise have been discharged.

## STATUS:

The ACE technology was accepted into the SITE Emerging Technology Program in July 1988. The laboratory-scale testing was completed in June 1992. The Emerging Technology Bulletin (EPA/540/F-92/011) and Emerging Technology Summary (EPA/540/S-93/504) are available from EPA. The research results are described in the *Journal of Air and Waste Management*, Volume 43, May 1993, pp. 784-789, "Alternating Current Electrocoagulation for Superfund Site Remediation."

Experiments on metals and complex synthetic slurries have defined major operating parameters for broad classes of waste streams. The technology has been modified to minimize electrical power consumption and maximize effluent throughput rates.

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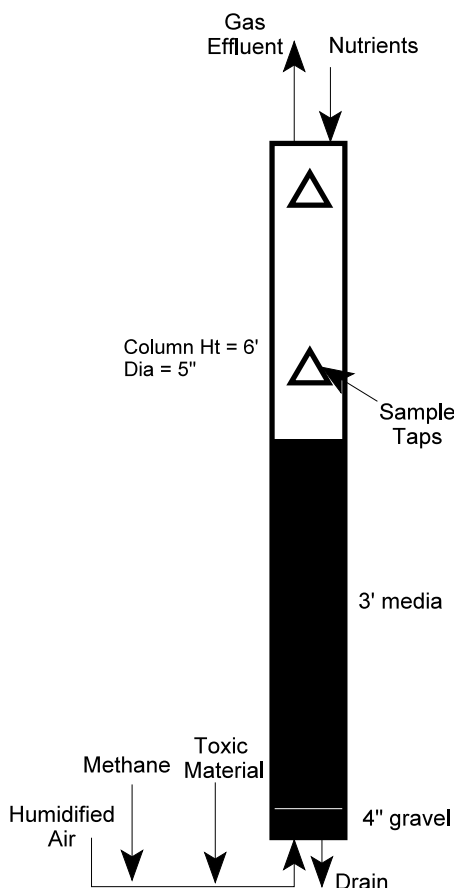
## REMEDATION TECHNOLOGIES, INC. (Biofilm Reactor for Chlorinated Gas Treatment)

### TECHNOLOGY DESCRIPTION:

The Remediation Technologies, Inc., biological treatment technology uses aerobic cometabolic organisms in fixed-film biological reactors to treat gases contaminated with volatile chlorinated hydrocarbons. Contaminated gases enter the bottom of the 6-foot-tall reactor column and flow up through a medium that has a high surface area and favorable porosity for gas distribution. Both methanotrophic and phenol-degrading organisms have been evaluated within the reactor. The figure below illustrates a methanotrophic reactor.

In methanotrophic columns, methane and nutrients are added to grow the organisms capable of degrading volatile chlorinated hydrocarbons.

The organisms degrade these compounds into acids and chlorides that can be subsequently degraded to carbon dioxide and chloride. Because of intermediate toxicity and competitive inhibition, methane-volatile organic compound (VOC) feeding strategies are critical to obtain optimum VOC degradation over the long term.



Methanotrophic bacteria from various soils were tested to determine potential VOC compound degradation. The optimal culture from this testing was isolated and transferred to a bench-scale biofilm reactor, where substrate degradation rates per unit of biofilm surface area were determined. Four pilot-scale biofilm reactors were then established, with feeding strategies and retention times based on earlier testing.

The following issues are investigated in the methanotrophic biofilm reactors:

- Comparison of different media types
- Trichloroethene (TCE) removal across the columns
- TCE degradation rates

In addition to studies of the methanotrophic biofilm reactors, a column was seeded with a filamentous phenol-degrading consortia that grows well on phenol in a nitrogen-limited solution. Phenol also induces enzymes capable of rapid cometabolic degradation of TCE.

### **WASTE APPLICABILITY:**

This technology can treat gaseous streams of volatile chlorinated hydrocarbons. These waste streams may result from air stripping of contaminated groundwater or industrial process streams, or from vacuum extraction during in situ site remediation.

### **STATUS:**

This technology was accepted into the SITE Emerging Technology Program in summer 1992; the evaluation was completed in 1995. The Emerging Technology Report, which details results from the evaluation, is being prepared.

TCE degradation rates in the pilot-scale biofilm reactor were well below those previously measured in laboratory testing or those reported in the literature for pure cultures. The phenol-fed column was started on a celite medium. TCE removal was superior to that in the methanotrophic columns, even with sub-optimal biomass development.

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**RESOURCE MANAGEMENT & RECOVERY**  
**(formerly Bio-Recovery Systems, Inc.)**  
**(AlgaSORB® Biological Sorption)**

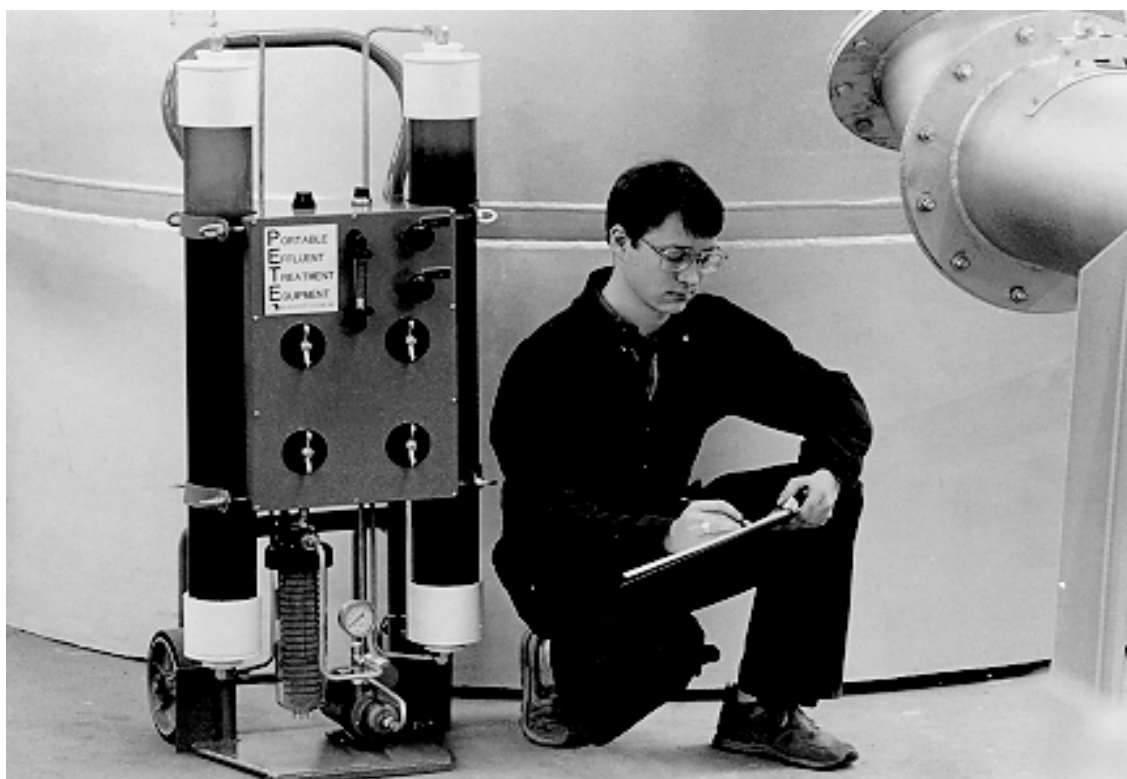
**TECHNOLOGY DESCRIPTION:**

The AlgaSORB® sorption process uses algae to remove heavy metal ions from aqueous solutions. The process takes advantage of the natural affinity for heavy metal ions exhibited by algal cell structures.

The photograph below shows a portable effluent treatment equipment (PETE) unit, consisting of two columns operating either in series or in parallel. Each column contains 0.25 cubic foot of AlgaSORB®, the treatment medium. The PETE unit shown below can treat waste at a flow rate of approximately 1 gallon per minute (gpm). Larger systems have been designed and manufactured to treat waste at flow rates greater than 100 gpm.

The AlgaSORB® medium consists of dead algal cells immobilized in a silica gel polymer. This immobilization serves two purposes: (1) it protects the algal cells from decomposition by other microorganisms, and (2) it produces a hard material that can be packed into columns that, when pressurized, still exhibit good flow characteristics.

The AlgaSORB® medium functions as a biological ion-exchange resin to bind both metallic cations (positively charged ions, such as mercury [ $\text{Hg}^{+2}$ ]) and metallic oxoanions (negatively charged, large, complex, oxygen-containing ions, such as selenate [ $\text{SeO}_4^{-2}$ ]). Anions such as chlorides or sulfates are only weakly bound or not bound at all. In contrast to current ion-exchange technology, divalent cations



Portable Effluent Treatment Equipment (PETE) Unit

typical of hard water, such as calcium ( $\text{Ca}^{+2}$ ) and magnesium ( $\text{Mg}^{+2}$ ), or monovalent cations, such as sodium ( $\text{Na}^{+}$ ) and potassium ( $\text{K}^{+}$ ) do not significantly interfere with the binding of toxic heavy metal ions to the algae-silica matrix.

Like ion-exchange resins, AlgaSORB<sup>®</sup> can be regenerated. After the AlgaSORB<sup>®</sup> medium is saturated, the metals are removed from the algae with acids, bases, or other suitable reagents. This regeneration process generates a small volume of solution containing highly concentrated metals. This solution must undergo treatment prior to disposal.

### WASTE APPLICABILITY:

This technology can remove heavy metal ions from groundwater or surface leachates that are "hard" or that contain high levels of dissolved solids. The process can also treat rinse waters from electroplating, metal finishing, and printed circuit board manufacturing operations. Metals removed by the technology include aluminum, cadmium, chromium, cobalt, copper, gold, iron, lead, manganese, mercury, molybdenum, nickel, platinum, selenium, silver, uranium, vanadium, and zinc.

### STATUS:

This technology was accepted into the Emerging Technology Program in 1988; the evaluation was completed in 1990. Under the Emerging Technology Program, the AlgaSORB<sup>®</sup> sorption process was tested on mercury-contaminated groundwater at a hazardous waste site in Oakland, California. Testing was designed to determine optimum flow rates, binding capacities, and the efficiency of stripping agents. The Emerging Technology Report (EPA/540/5-90/005a&b), Emerging Technology Summary (EPA/540/ S5-90/005), and Emerging Technology Bulletin (EPA/540/F-92/003) are available from EPA. An article was also published in the *Journal of Air and Waste Management*, Volume 41, No. 10, October 1991.

Based on results from the Emerging Technology Program, Resource Management & Recovery was invited to participate in the SITE Demonstration Program.

The process is being commercialized for groundwater treatment and industrial point source treatment.

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**ROY F. WESTON, INC.**  
**(Ambersorb® 563 Adsorbent)**

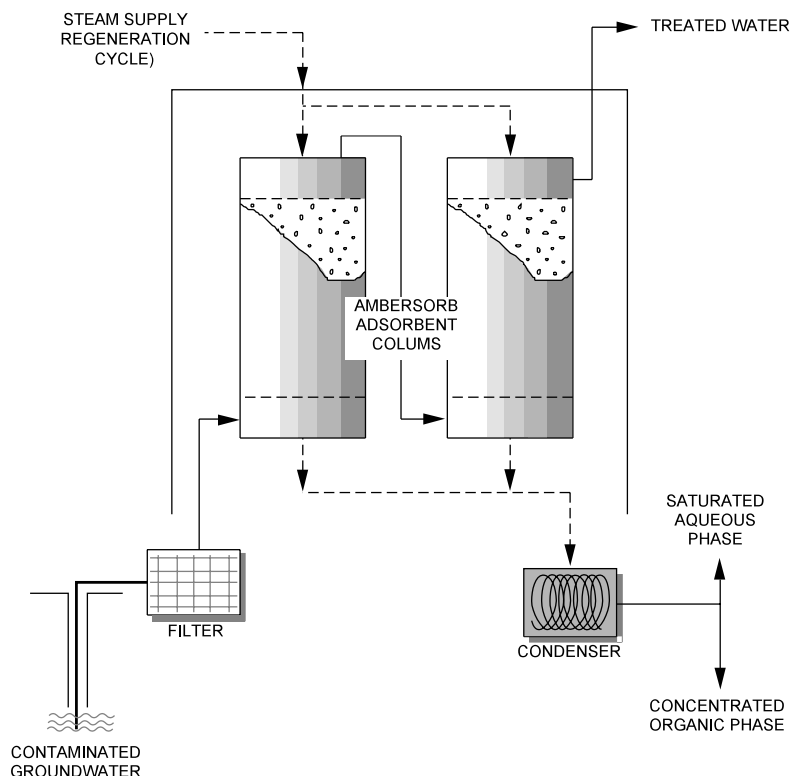
**TECHNOLOGY DESCRIPTION:**

Ambersorb® 563 adsorbent is a regenerable adsorbent that treats groundwater contaminated with hazardous organics (see figure below). Ambersorb® 563 adsorbent has 5 to 10 times the capacity of granular activated carbon (GAC) for low concentrations of volatile organic compounds (VOC).

Current GAC adsorption techniques require either disposal or thermal regeneration of the spent carbon. In these cases, the GAC must be removed from the site and shipped as a hazardous material to the disposal or regeneration facility.

Ambersorb® 563 adsorbent has unique properties that provide the following benefits:

- Ambersorb® 563 adsorbent can be regenerated on site using steam, thus eliminating the liability and cost of off-site regeneration or disposal associated with GAC treatment. Condensed contaminants are recovered through phase separation.
- Because Ambersorb® 563 adsorbent has a much higher capacity than GAC for volatile organics (at low concentrations), the process can operate for significantly longer service cycle times before regeneration is required.



Ambersorb® 563 Adsorbent

- Ambersorb® 563 adsorbent can operate at higher flow rate loadings than GAC, which translates into a smaller, more compact system.
- Ambersorb® 563 adsorbents are hard, nondusting, spherical beads with excellent physical integrity, eliminating handling problems and attrition losses typically associated with GAC.
- Ambersorb® 563 adsorbent is not prone to bacterial fouling.
- Ambersorb® 563 adsorbent has extremely low ash levels.

In addition, the Ambersorb® 563 carbonaceous adsorbent-based remediation process can eliminate the need to dispose of by-products. Organics can be recovered in a form potentially suitable for immediate reuse. For example, removed organics could be burned for energy in a power plant.

### **WASTE APPLICABILITY:**

Ambersorb 563 adsorbent is applicable to any water stream containing contaminants that can be treated with GAC, such as 1,2-dichloroethane, 1,1,1-trichloroethane, tetrachloroethene, vinyl chloride, xylene, toluene, and other VOCs.

### **STATUS:**

This technology was accepted into the SITE Emerging Technology Program in 1993. The Emerging Technology Bulletin (EPA/540/F-95/500), the Emerging Technology Summary (EPA/540/SR-95/516), and the Emerging Technology Report (EPA/540/R-95/516) are available from EPA.

The Ambersorb® 563 technology evaluation was conducted at the former Pease Air Force Base in Newington, New Hampshire. The groundwater

contained vinyl chloride, 1,1-dichloroethene, and trichloroethene. The field study was conducted over a 12-week period. The tests included four service cycles and three steam regenerations. The effluent from the Ambersorb® adsorbent system consistently met drinking water standards. On-site steam regeneration demonstrated that the adsorption capacity of the Ambersorb® system remained essentially unchanged following regeneration.

### **FOR FURTHER INFORMATION:**

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Note: Ambersorb® is a registered trademark of Rohm and Haas Company.

**STATE UNIVERSITY OF NEW YORK AT OSWEGO,  
ENVIRONMENTAL RESEARCH CENTER  
(Electrochemical Peroxidation of PCB-Contaminated Sediments and Waters)**

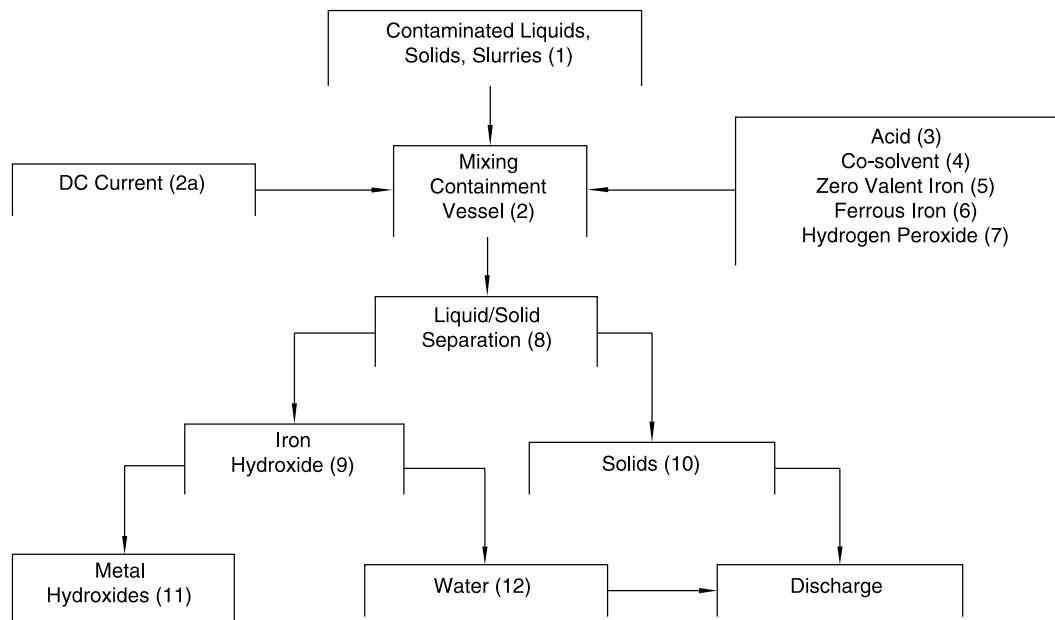
**TECHNOLOGY DESCRIPTION:**

The Environmental Research Center at the State University of New York at Oswego (SUNY) has developed an electrochemical peroxidation process widely applicable for the treatment of liquid wastes and slurries with low solids content. The process treats mixed waste by using (1) oxidative free radicals to attack organic contaminants, and (2) adsorptive removal of metals from liquid waste streams. Initial testing indicates destructive efficiencies greater than 99 percent for a variety of compounds including polychlorinated biphenyls (PCB), volatile organic compounds, benzene, toluene, ethylbenzene, xylene, MTBE, organic dyes, and microbes.

The process involves combining Fenton's reagent with a small electrical current. In a batch treatment process, steel electrodes are submersed into the waste to be treated; solid particles are suspended by mechanical mixing or stirring. Hydrogen peroxide and iron are introduced from the electrodes as a low direct current is applied.

The iron and hydrogen peroxide instantaneously react to form free radicals, which oxidize organic contaminants. Free radicals are also produced by the reaction of the peroxide with solvated electrons. The process can be significantly enhanced by pH adjustment, periodic current reversal, and use of proprietary enhancements.

Metals readily adsorb to the iron hydroxide by-product, and the metals can then be separated by precipitation or flocculation. The volume of by-products may be reduced and the metals may be removed by solids separation. In specific applications, select metals may be plated onto electrodes and recovered.



**Pilot-Scale Electrochemical Peroxidation System**

## WASTE APPLICABILITY:

This process is capable of treating liquids and slurries containing a variety of contaminants, including oxidizable organic compounds and metals. The process may be applied to industrial process wastes (textiles, pulp and paper, food industry), landfill leachates, gasoline- or solvent-contaminated groundwater, pesticide rinsates, or other liquid wastes.

## STATUS:

The technology was accepted into the SITE Emerging Technology Program in November 1993 to evaluate photochemical methods of destroying PCBs in water and sediment. The evaluation was complete in 1995.

During research related to the initial SITE evaluation, which focused on photocatalytic processes, a new technology (electrochemical peroxidation) was discovered. Electrochemical peroxidation has distinct advantages over photochemical processes, and its development was pursued. A pilot-scale continuous flow treatment system has been constructed with a local remediation firm and was tested at a gasoline-contaminated groundwater site in winter of 1998/99. In situ application of the process were conducted at a gasoline spill site during spring, 1999. The process was used to reduce chlorinated solvents (TCE, DCE, PCE) and petroleum hydrocarbons in contaminated groundwater at a large Air Force Base in 1998.

Since completing the SITE project, they have developed and are in the process of patenting a peroxide release system that can be deployed at remote sites to address chlorinated and non-chlorinated organic compounds in situ as well as add oxygen to the groundwater to affect aerobic degradation. This process uses a battery operated pump to inject  $H_2O_2$  into the groundwater to deliver a peroxide solution that readily changes a plume to an aerobic state at a fraction of the cost of other oxygen release

compounds. A pilot scale demonstration conducted at a Saratoga Springs site in New York on about 3,000,000 gallons of BTEX and MTBE contaminated groundwater reduced the contaminant concentrations to below detect within 6 months and increased the dissolved oxygen concentration from  $<0.5$  to  $>9.0$ .

Because  $H_2O_2$  is  $>90\%$  oxygen, the relative cost of the increased dissolved oxygen is about 1/3 that of commercially available oxygen release compounds. Additionally, in well inserts are now available to be used in existing 2.6" monitoring and/or recovery wells to slowly, gravity or pump release a peroxide solution to the groundwater to affect in situ Fenton's Reagent Reactions and alter the redox of the impacted groundwater. These products are currently available through EBSI, a New Jersey based remediation firm.

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**THERMATRIX, INC.**  
**(formerly PURUS, INC.)**  
**(Photolytic Oxidation Process)**

**TECHNOLOGY DESCRIPTION:**

The photolytic oxidation process indirectly destroys volatile organic compounds (VOC) in soil and groundwater. The process uses a xenon pulsed-plasma flash-lamp that emits short wavelength ultraviolet (UV) light at very high intensities. The process strips the contaminants into the vapor phase, and the UV treatment converts the VOCs into less hazardous compounds.

Photolysis occurs when contaminants absorb sufficient UV light energy, transforming electrons to higher energy states and breaking molecular bonds (see figure below). Hydroxyl radicals, however, are not formed. The process requires the UV light source to emit wavelengths in the regions absorbed by the contaminant. An innovative feature of this technology is its ability to shift the UV spectral output to optimize the photolysis.

The process uses vacuum extraction or air stripping to volatilize VOCs from soils or groundwater, respectively. VOCs then enter the photolysis reactor, where a xenon flashlamp generates UV light. The plasma is produced by pulse discharge of electrical energy across two electrodes in the lamp. Ninety-nine percent destruction occurs within seconds, allowing continuous operation. Because organics are destroyed in the vapor phase, the process uses less energy than a system treating dissolved organics.

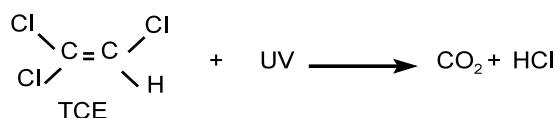
**WASTE APPLICABILITY:**

The photolytic oxidation process is designed to destroy VOCs, including dichloroethene (DCE), tetrachloroethene (PCE), trichloroethene (TCE), and vinyl chloride volatilized from soil or groundwater. Destruction of other VOCs, such as benzene, carbon tetrachloride, and 1,1,1-trichloro-ethane, is under investigation.

**STATUS:**

The photolytic oxidation process was accepted into the SITE Emerging Technology Program in March 1991. Field testing of a full-scale prototype began in October 1991. The test was conducted at the Lawrence Livermore National Laboratory Superfund site in California. The site contains soil zones highly contaminated with TCE.

During the field test, a vacuum extraction system delivered contaminated air to the unit at air flows up to 500 cubic feet per minute (cfm). Initial TCE concentrations in the air were approximately 250 parts per million by volume. The contaminant removal goal for the treatment was 99 percent. Vapor-phase carbon filters were placed downstream of the unit to satisfy California Air Quality emission control requirements during the field test. Test results are discussed below. The Final Report (EPA/540/R-93/516), the Summary Report (EPA/540/SR-93/516), and the Technology Bulletin (EPA/540/F-93/501) have been published.



UV Photolysis of TCE

The low-wavelength UV emissions allowed direct photolysis of many VOCs, particularly chlorinated compounds and freons, that would not have been possible with commercial mercury vapor lamps. TCE, PCE, and DCE were quickly destroyed. To be rapidly photolyzed, some VOCs require photosensitization or an even lower-wavelength light source.

TCE results are shown in the table below. TCE removal yielded undesirable intermediates. Greater than 85 percent of the TCE chain photo-oxidation product is dichloroacetyl chloride (DCAC). Further oxidation of DCAC is about 100 times slower than TCE photolysis and forms dichlorocarbonyl (DCC) at about 20 percent yield. At this treatment level, the DCC concentration may be excessive, requiring additional treatment. Further studies should focus on (1) the effectiveness of dry or wet scrubbers for removing acidic photo-oxidation products, (2) development of thermal or other methods for posttreatment of products such as DCAC, and (3) the use of shorter-wavelength UV lamps or catalysts to treat a broader range of VOCs.

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## TRINITY ENVIRONMENTAL TECHNOLOGIES, INC. (PCB- and Organochlorine-Contaminated Soil Detoxification)

### TECHNOLOGY DESCRIPTION:

This technology uses an aprotic solvent, other reagents, and heat to dehalogenate polychlorinated biphenyls (PCB) in solids to inert biphenyl and chloride salts (see figure below). First, solid material is sized to allow better contact between the reagents and PCBs. In a continuous flow reactor, the soils are heated to drive off excess water. Reagents are then added to destroy the PCBs.

The reagent, consisting of a solvent and an inorganic alkali material, completely strips chlorine from the PCB molecule. Excess alkali can be easily neutralized and is reusable in the process. Treated soil can be returned to the excavation once analytical results show that PCBs have been destroyed.

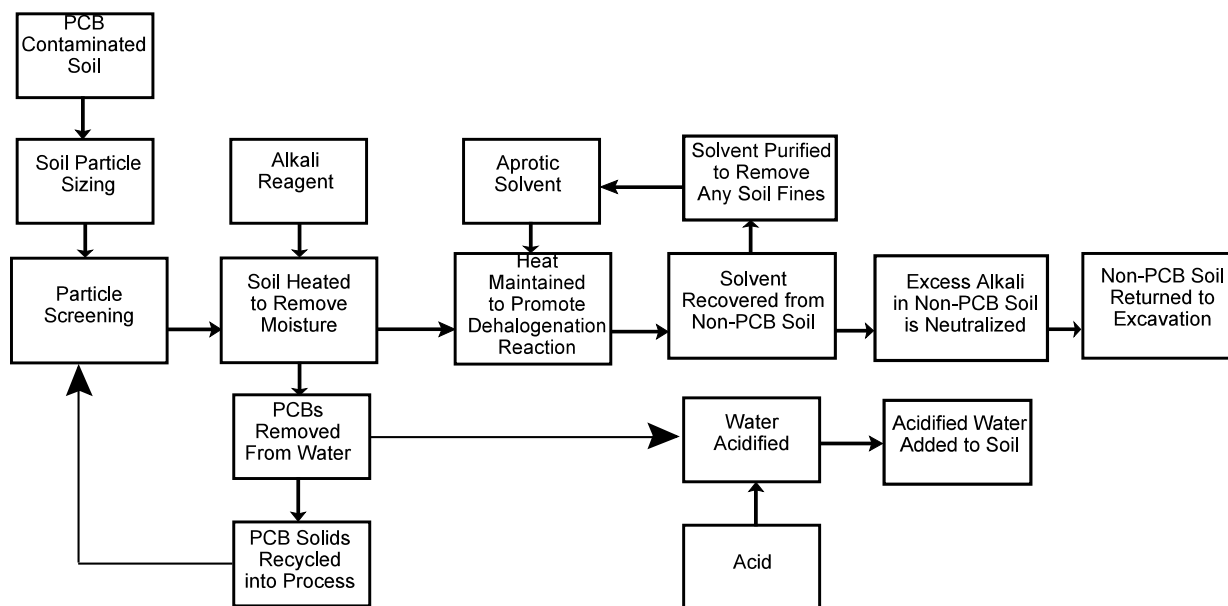
Gas chromatography/mass spectroscopy analyses of processed PCB materials show that the process produces no toxic or hazardous products.

A chlorine balance confirms that PCBs are completely dehalogenated. To further confirm chemical dehalogenation, inorganic and total organic chloride analyses are also used. The average total chloride recovery for treated soils is greater than 90 percent.

The commercial process is expected to be less costly than incineration but more expensive than land disposal. Since no stack emissions are produced, permitting the process for a remediation would be easier than incineration.

### WASTE APPLICABILITY:

The process can treat many different solid and sludge-type materials contaminated with PCB Aroclor mixtures, specific PCB congeners, pentachlorophenol, and individual chlorinated dioxin isomers. However, other chlorinated hydrocarbons such as pesticides, herbicides, and polychlorinated dibenzofurans could also be treated by this technology.



PCB Soil Detoxification Process

## STATUS:

This technology was accepted into the SITE Emerging Technology Program in July 1990. The current system was developed by researchers in early 1991, after the original aqueous, caustic-based system proved ineffective at destroying PCBs.

The SITE project was completed in 1992. Trinity is investigating further improvements to the technology. Due to cost limitations, no commercialization of the investigated process is expected. A final report will not be published.

In bench-scale studies, synthetically contaminated materials have been processed to eliminate uncertainties in initial PCB concentration. This chemical process has reduced PCB concentrations from 2,000 parts per million (ppm) to less than 2 ppm in about 30 minutes using moderate power input. Further laboratory experiments are underway to determine the reaction mechanism and to enhance PCB destruction. Through additional experimentation, Trinity Environmental Technologies, Inc., expects to reduce processing time through better temperature control, more efficient mixing, and possibly more aggressive reagents.

A modular pilot-scale processor has been planned that uses several heating zones to preheat and dry the contaminated soil, followed by PCB destruction. The pilot process would be capable of processing 1 ton per hour initially. Additional modules could be added to increase process capacity, as needed. Contaminated soils from actual sites will be used to test the pilot-scale processor instead of the synthetically contaminated soils used in bench-scale testing.

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## UNITED KINGDOM ATOMIC ENERGY AUTHORITY (formerly AEA Technology Environment) (Soil Separation and Washing Process)

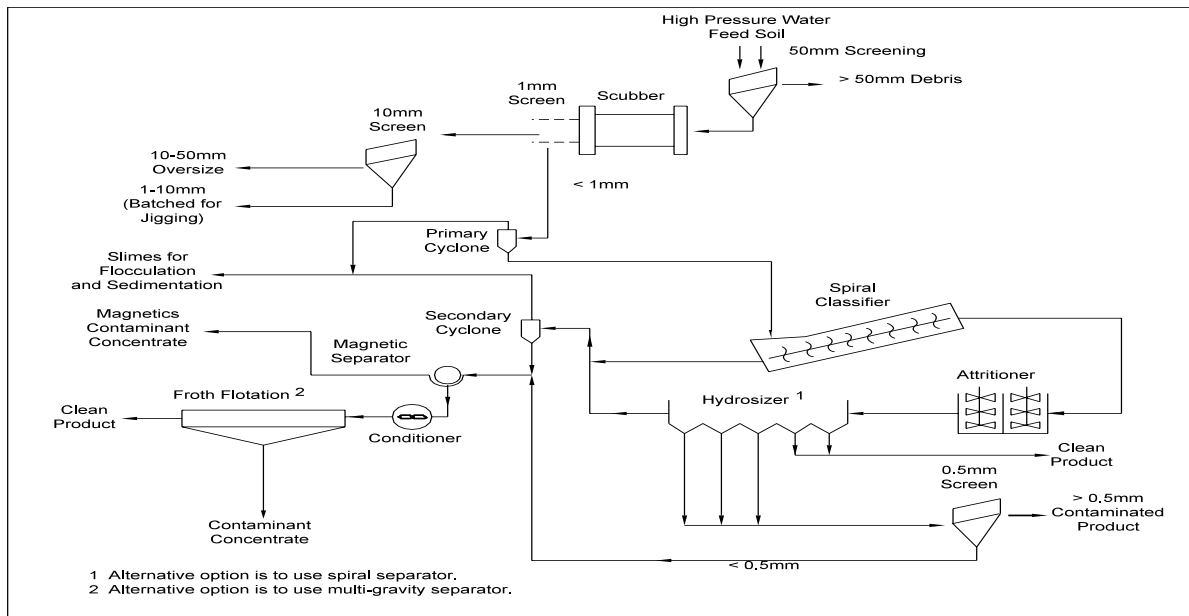
### TECHNOLOGY DESCRIPTION:

AEA Technology Environment (AEA) has developed an ex situ soil separation and washing process that uses mineral processing technology and hardware. The process can be used (1) as a volume reduction process to release clean soil fractions and concentrate contaminants, or (2) as a pretreatment stage in a treatment train.

Because each contaminated soil is different, AEA has developed a custom physical treatment process for soil using a three-stage process: laboratory-scale characterization, separation testing and assessment, and treatment and data analysis.

AEA is experienced in conducting pilot plant testing programs on contaminated soil and mineral ores. In addition, AEA uses computer software designed to reconcile material flow data. The results of data processing lead to recommendations for full-scale

continuous flow sheets with predicted flows of solids, associated contaminant species, and water. Contaminant levels and distributions to the various products can also be estimated. Such data are required to estimate the cost and potential success of the full-scale remediation process plant. Flow sheet configuration is flexible and can be customized to address the nature and contamination of each soil or waste. A typical schematic flow sheet of the process is shown in the diagram on the previous page. The flow sheet involves screening the raw feed at 50 millimeters (mm) under powerful water jets to deagglomerate the mass. Debris greater than 50 mm in size is often decontaminated. Remaining solids and the water are passed through a drum scrubber that deagglomerates the mass further because agitation is more intense. It breaks down clay lumps and adhering material into suspension, except for surface coatings of clay and oil on fine particles. The drum scrubber discharge is screened at 1 mm, and the oversize discharge is screened at 10 mm. The 10 to 50 mm size range is often clean debris; if it is not clean then it can



Generalized Flowsheet for the Physical Treatment of Contaminated Soil

be crushed and refeed to the system. Material from 1 to 10 mm is often contaminated and requires further treatment.

For all material less than 1 mm, the clay and water are removed by hydrocycloning. The fine product, less than 10 micrometers (m), is flocculated and thickened to recover the process water for recycling. Thickened clay product, usually containing concentrated contaminants, passes to further treatment or disposal. Sands from the hydrocycloning step are further dewatered in a classifier before the third and most intense deagglomeration operation.

An attrition scrubber removes the remaining surface contamination and degrades fine clayballs. Having completed deagglomeration, the soil is fractionated by particle size or separated by specific gravity. A second stream of particles less than 10 mm is removed by hydrocycloning and joins the primary product stream. Finer sands and silt are screened at 500 mm to yield a contaminated sand for disposal or retreatment. A 10 to 500 mm fraction can be separated magnetically, by flotation, by multigravity separation, or by a combination of these methods. These stages produce a contaminant concentrate, leaving the remaining material relatively contaminant free.

The soil separation and washing process is designed to remove metals, petroleum hydrocarbons, and polynuclear aromatic hydrocarbons from soil. The process may be applied to soils from gas and coke works, petrochemical plants, coal mines, iron and steel works, foundries, and nonferrous smelting, refining, and finishing sites. The process can also treat sediments, dredgings, sludges, mine tailings, and some industrial wastes.

## **STATUS:**

The technology was accepted into the SITE Emerging Technology Program in July 1991 and completed in 1994. A Final Report was delivered to the U.S. EPA in 1994, and work done with this technology was presented the same year at the 87<sup>th</sup> Annual Meeting and Exhibition of the Air and Waste Management Association, the 20<sup>th</sup> Annual RREL Hazardous Waste Research Symposium, and the 5<sup>th</sup> Forum on Innovative Hazardous Waste Treatment Technologies: Domestic and International. Pilot trials were conducted on 30 tons of soil at a throughput rate of 0.5 ton per hour. Several test runs were performed to evaluate different flow sheet configurations. Reports on this technology can be obtained from the U.S. EPA.

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## UNIVERSITY OF DAYTON RESEARCH INSTITUTE (Photothermal Detoxification Unit)

### TECHNOLOGY DESCRIPTION:

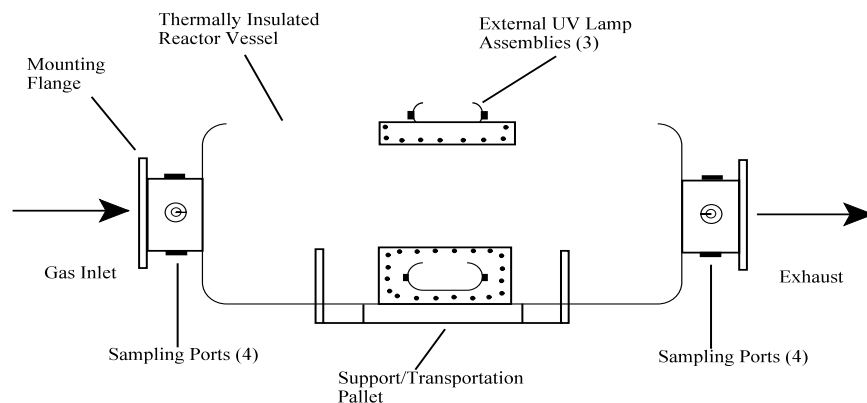
Photolytic reactions (reactions induced by exposure to ultraviolet [UV] light) can destroy certain hazardous organic wastes at relatively low temperatures. However, most photochemical processes offer relatively limited throughput rates and cannot completely mineralize the targeted wastes. For aqueous waste streams, these problems have been partially addressed by using indirect photochemical reactions involving a highly reactive photolytic initiator such as hydrogen peroxide or heterogeneous catalysts. Recently, the University of Dayton Research Institute (UDRI) developed a photolytic detoxification process to treat the gas waste streams. This process is clean and efficient and offers the speed and general applicability of a combustion process.

The photothermal detoxification unit (PDU) uses photothermal reactions conducted at temperatures higher than those used in conventional photochemical processes (200 to 500°C versus 20°C), but lower than combustion temperatures (typically greater than 1,000°C). At these elevated temperatures, photothermal reactions are energetic enough to destroy many wastes quickly and efficiently without producing complex and potentially hazardous by-products.

The PDU is a relatively simple device, consisting of an insulated reactor vessel illuminated with high-intensity UV lamps. As shown in the figure below, the lamps are mounted externally for easy maintenance and inspection. Site remediation technologies that generate high-temperature gas streams, such as thermal desorption or in situ steam stripping, can incorporate the PDU with only slight equipment modifications. The PDU can be equipped with a pre-heater for use with soil vapor extraction (SVE). Furthermore, the PDU can be equipped with conventional air pollution control devices for removal of acids and suspended particulates from the treated process stream. The PDU shown in the figure below is also equipped with built-in sampling ports for monitoring and quality assurance and quality control.

### WASTE APPLICABILITY:

According to UDRI, the PDU has proven extremely effective at destroying the vapors of polychlorinated biphenyls, polychlorinated dibenzodioxins, polychlorinated dibenzofurans, aromatic and aliphatic ketones, and aromatic and aliphatic chlorinated solvents, as well as brominated and nitrous wastes found in soil, sludges, and aqueous streams. The PDU can be incorporated with most existing and proposed



Photothermal Detoxification Unit (PDU)

remediation processes for clean, efficient, on-site destruction of the off-gases. More specifically, high-temperature processes can directly incorporate the PDU; SVE can use the PDU fitted with a preheater; and groundwater remediation processes can use the PDU in conjunction with air stripping.

## STATUS:

The technology was accepted into the Emerging Technology Program in August 1992, and development work began in December 1992. The evaluation was completed in 1994. The Emerging Technology Report (EPA/540/R-95/526), the Emerging Technology Bulletin (EPA/540/F-95/505) and the Emerging Technology Summary (EPA/540/SR-95/526) are available from EPA. An article was also published in the *Journal of Air and Waste Management*, Volume 15, No. 2, 1995.

Emerging Technology Program data indicate that the technology performs as expected for chlorinated aromatic wastes, such as dichlorobenzene and tetrachloro-dibenzodioxin, and better than expected for relatively light chlorinated solvents, such as trichloroethene (TCE) and tetrachloroethene. Further tests with selected mixtures, including benzene, toluene, ethyl-benzene, xylene, TCE, dichlorobenzene, and water vapor, show that the process is effective at treating wastes typically found at many remediation sites. Adequate scaling and performance data are now available to proceed with the design and development of prototype full-scale units for field testing and evaluation.

Through prior programs with the U.S. Department of Energy, technology effectiveness has been thoroughly investigated using relatively long wavelength UV light (concentrated sunlight with wavelengths greater than 300 nanometers). Limited data have also been generated at shorter wavelengths (higher energy) using available industrial UV illumination systems.

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## UNIVERSITY OF HOUSTON (Concentrated Chloride Extraction and Recovery of Lead)

### TECHNOLOGY DESCRIPTION:

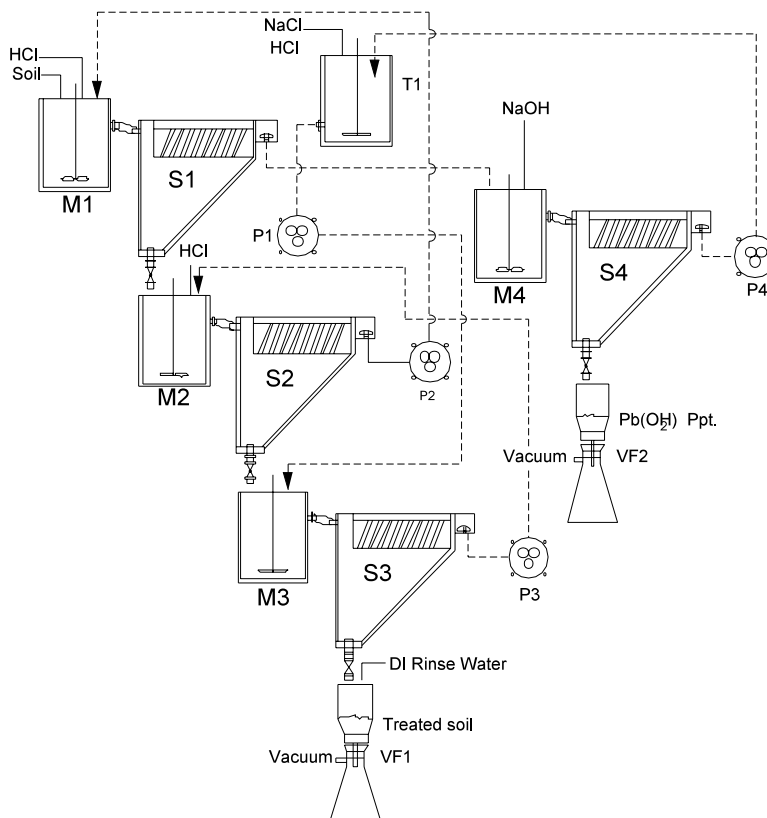
This technology recovers lead from soils using an aqueous solvent extraction process that takes advantage of the high solubility of chlorocomplexes of lead. The extract solution contains greater than 4 molar sodium chloride and operates at a pH of 4. The figure below depicts a bench-scale model of the three-stage continuous countercurrent pilot plant used to study the process.

To operate the pilot plant, soil is sieved to remove particles greater than 1.12 millimeters in diameter. The soil is then placed in the first chloride extraction tank (M1) for extraction with concentrated chloride solution. The resulting soil and solvent slurry passes

into a thickener (S1). The soil and solvent slurry has an average residence time of 1 hour in each extraction tank in the system.

The bottoms of the thickener flow by gravity to the second chloride extraction tank (M2). The solution exiting the second chloride extraction tank flows to the second thickener (S2). The bottoms of the second thickener feed the third stage.

The third stage is the last soil stage and the first solvent stage; fresh solvent enters the system at stage three. The bottoms of the third thickener (S3) flow by gravity into the soil rinse system (VF1) to remove excess salt. Soil rinsed in VF1 is clean product soil. The overflows from S3 pass to M2, the overflows from S2 pass to the M1, and the overflows from S1



Concentrated Chloride Extraction and Recovery  
of Lead (Bench-Scale Process)

pass to the lead precipitation system (M4/S4). In M4/S4, lead hydroxide  $[\text{Pb}(\text{OH})_2]$  is recovered by simply raising the pH of the spent extraction solution to 10. After  $\text{Pb}(\text{OH})_2$  removal, the spent chloride solution flows to the solvent makeup unit (T1) where it is acidified to pH 4 in preparation for reuse.

This technology produces (1) treated soil, suitable for replacement on site, and (2)  $\text{Pb}(\text{OH})_2$  that may be suitable for reprocessing to recover pure lead. The ease of solvent regeneration minimizes waste disposal. Solvent recycling is very successful, and pilot-plant tests have required little or no salt or water makeup.

The pilot plant has treated soil from two lead battery waste sites (LBWS). One LBWS soil contained a high percentage of fines (about 50 percent clay and silt), and the other contained a low percentage of fines (less than 20 percent clay and silt). The pilot plant's method of transferring soil by gravity eases much of the soil handling problems typical of high clay soils. After treatment, both soils easily passed the Toxicity Characteristic Leaching Procedure test. The total lead concentration in the high fines and low fines soil was reduced from 7 percent to about 0.15 percent and from 1.5 percent to 0.07 percent, respectively.

### **WASTE APPLICABILITY:**

This technology removes high concentrations of lead from soil, particularly at LBWS, while producing a treated soil that can be used as backfill and a recyclable, concentrated lead salt.

### **STATUS:**

This technology was accepted into the SITE Emerging Technology Program in September 1994. Batch extraction testing was completed in 1995. Treatability tests using the pilot plant to process high and low fines soils were completed in August 1996. The high fines soil came from a LBWS located in Houston, Texas, and the low fines soil came from the Sapp Battery National Priority List site in Florida. Future plans include expanding the applications of the technology by studying its effect on other wastes in soils. The technology evaluation was scheduled to be completed by August 1998.

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## UNIVERSITY OF SOUTH CAROLINA (In Situ Mitigation of Acid Water)

### TECHNOLOGY DESCRIPTION:

The in situ acid water mitigation process addresses the acid drainage problem associated with exposed sulfide-bearing minerals from sources including mine waste rock and abandoned metallic mines. Acid drainage forms under natural conditions when iron disulfides are exposed to the atmosphere and water, spontaneously oxidizing them to produce a complex of highly soluble iron sulfates and salts. These salts hydrolyze to produce an acid-, iron-, and sulfate-enriched drainage that adversely affects the environment.

The in situ mitigation strategy modifies the hydrology and geochemical conditions of the site through land surface reconstruction and selective placement of limestone.

Limestone is used as the alkaline source material because it has long-term availability, is generally inexpensive, and is safe to handle. For the chemical balances to be effective, the site must receive enough rainfall to produce seeps or drainages that continually contact the limestone. Rainfall, therefore, helps to remediate the site, rather than increasing the acid drainage.

During mine construction, lysimeters and limestone chimneys are installed to collect surface runoff and funnel it into the waste rock dump. Acidic material is capped with impermeable material to divert water from the acid cores. This design causes the net acid load to be lower than the alkaline load, resulting in benign, nonacid drainage.



Overview of Site Lysimeters

## **WASTE APPLICABILITY:**

The technology mitigates acid drainage from abandoned waste dumps and mines. It can be applied to any site in a humid area where limestone is available.

## **STATUS:**

This technology was accepted into the SITE Emerging Technology Program in March 1990. Studies under the Emerging Technology Program are complete. A peer-reviewed journal article has been prepared and submitted.

For the SITE evaluation, six large-scale lysimeters (12 feet wide, 8 feet high, and 16 feet deep) were constructed and lined with 20-mil polyvinyl chloride plastic (see photograph on previous page). The lysimeters drained through an outlet pipe into 55-gallon collection barrels. Piezometers in the lysimeter floor monitored the hydrology and chemistry of the completed lysimeter. During June 1991, 50 tons of acid-producing mine waste rock was packed into each lysimeter.

The effluent from each lysimeter was monitored for 1 year to establish a quality baseline. In the second phase of the study, selected lysimeters were topically treated, maintaining two lysimeters as controls to compare the efficacy of the acid abatement strategy. In addition, a rain gauge was installed at the site for mass balance measurements. An ancillary study correlating laboratory and field results is complete.

In the last phase of the 3-year study, little if any leachate was collected due to drought conditions in the southeast U.S. With the return of normal rainfall, sufficient leachate was collected to compare the treated lysimeters against the controls to evaluate the treatment's effectiveness. The treated lysimeters, in general, showed a 20 to 25 percent reduction in acid formation. The acidities measured about 10,000 milligrams per liter (mg/L) for the untreated lysimeters, while acidities from the treated lysimeters measured about 7,000 mg/L. This study was conducted on a very high acid-producing waste rock, representing a near worst-case situation. The process should be more successful on milder acid sources.

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**UNIVERSITY OF WASHINGTON**  
**(Adsorptive Filtration)****TECHNOLOGY DESCRIPTION:**

Adsorptive filtration removes inorganic contaminants (metals) from aqueous waste streams. An adsorbent ferrihydrite is applied to the surface of an inert substrate such as sand, which is then placed in one of three vertical columns (see figure below). The contaminated waste stream is adjusted to a pH of 9 to 10 and passed through the column. The iron-coated sand grains in the column act simultaneously as a filter and adsorbent. When the column's filtration capacity is reached (indicated by particulate breakthrough or column blockage), the column is backwashed. When the adsorptive capacity of the column is reached (indicated by break-through of soluble metals), the metals are removed and concentrated for subsequent recovery with a pH-induced desorption process.

Sand can be coated by ferrihydrite formed when either iron nitrate or iron chloride salts react with sodium hydroxide. The resulting ferrihydrite-coated sand is insoluble at a pH greater than 1; thus, acidic solutions can be used in the regeneration step to ensure complete metal recovery. The system does not appear to lose treatment efficiency after numerous regeneration cycles. Anionic metals such as arsenate, chromate, and selenite can be removed from the solution by treating it at a pH near 4 and regenerating it at a high pH. The system has an empty bed retention time of 2 to 5 minutes.

This technology offers several advantages over conventional treatment technologies. These advantages are its ability to (1) remove both dissolved and suspended metals from the waste stream, (2) remove a variety of metal complexes, (3) work in the presence of high concentrations of background ions, and (4) remove anionic metals.

**WASTE APPLICABILITY:**

This adsorptive filtration process removes inorganic contaminants, consisting mainly of metals, from aqueous waste streams. It can be applied to aqueous waste streams with a wide range of contaminant concentrations and pH values.

**STATUS:**

This technology was accepted into the SITE Emerging Technology Program in January 1988; the evaluation was completed in 1992. The Emerging Technology Report (EPA/540/R-93/515), Emerging Technology Summary (EPA/540/SR-93/515), and Emerging Technology Bulletin (EPA/540/F- 92/008) are available from EPA.

During the SITE evaluation, synthetic solutions containing cadmium, copper, or lead at concentrations of 0.5 part per million (ppm) were treated in packed columns using 2-minute retention times. After approximately 5,000 bed volumes were treated, effluent concentrations were about 0.025 ppm for each metal, or a 95 percent removal efficiency. The tests were stopped, although the metals were still being removed. In other experiments, the media were used to adsorb copper from wastewater containing about 7,000 milligrams per liter (mg/L) copper.

The first batch of regenerant solutions contained cadmium and lead at concentrations of about 500 ppm. With initial concentrations of 0.5 ppm, this represents a concentration factor of about 1,000 to 1. Data for the copper removal test have not been analyzed. At a flow rate yielding a 2-minute retention time, the test would have taken about 7 days of continuous flow operation to treat 5,000 bed volumes. Regeneration took about 2 hours.

The system has also been tested for treatment of rinse waters from a copper-etching process at a printed circuit board shop. The coated sand was effective in removing mixtures of soluble, complexed, and particulate copper, as well as zinc and lead, from these waters. When two columns were used in series, the treatment system was able to handle fluctuations in influent copper concentration from less than 10 mg/L up to several hundred mg/L.

Groundwater from Western Processing, a Superfund site near Seattle, Washington, was treated to remove both soluble and particulate zinc.

Recent tests have shown that the technology can be used to remove heavy metals selectively from waste solutions that contain orders of magnitude of higher concentrations of Al, and that it can be used to remove Sr from highly alkaline wastewater (pH>14, for example, alkaline nuclear wastes).

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### **TECHNOLOGY DEVELOPER CONTACT:**

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## UNIVERSITY OF WISCONSIN-MADISON (Photoelectrocatalytic Degradation and Removal)

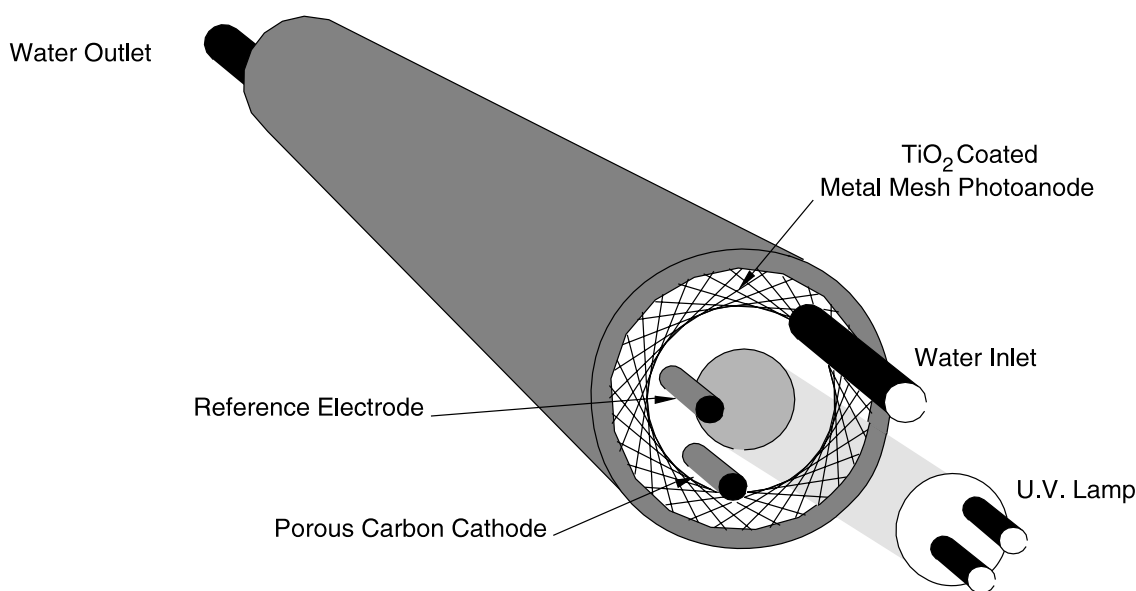
### TECHNOLOGY DESCRIPTION:

The University of Wisconsin-Madison (UW-Madison) is developing a photocatalytic technology that uses titanium dioxide ( $\text{TiO}_2$ ) suspensions to coat various supporting materials used in treatment applications. For this application, the suspensions are used to coat a conductive metallic or carbon mesh. Coating the mesh with a suitable thickness of  $\text{TiO}_2$  catalyst provides the basis for a photoreactor that uses most of the available ultraviolet (UV) radiation. An electrical field can also be applied across the catalyst to improve its performance.

The figure below shows a possible photoreactor design that uses a ceramic film. In this design, the  $\text{TiO}_2$  coating on the porous metal acts as a photoanode. An electric potential can then be placed across the coating to direct the flow of electrons to a porous carbon counter-electrode that has a high surface area and is capable of collecting collect any heavy metal ions present in the liquid. In addition, an applied electric potential can improve the destruction efficiency of

organic contaminants by reducing electron-hole recombination on the catalyst surface. This recombination is seen as a primary reason for the observed inefficiency of other UV/ $\text{TiO}_2$  systems used to treat organics in groundwater. Lastly, the electric potential has been shown to reduce the interference of electrolytes on the oxidation process. Electrolytes such as the bicarbonate ion are known hydroxyl radical scavengers and can be problematic in the UV/ $\text{TiO}_2$  treatment of contaminated groundwater.

This technology represents an improvement on liquid-phase photocatalytic technologies by distributing radiation uniformly throughout the reactor. Also, the technology does not require additional oxidants, such as peroxide or ozone, to cause complete mineralization or to improve reaction rates. It also eliminates the need for an additional unit to separate and recover the catalyst from the purified water after the reaction is complete.



Photoreactor Design using Ceramic Film

## WASTE APPLICABILITY:

This particular technology is designed to treat groundwater and dilute aqueous waste streams contaminated with organics and heavy metals. Organics are completely oxidized to carbon dioxide, water, and halide ions. Heavy metals are subsequently stripped from the cathode and recovered.

## STATUS:

The UW-Madison photocatalytic technology was accepted into the SITE Emerging Technology Program in 1995. The overall objective of the Emerging Technology Program study is to refine the reactor design, enabling it to treat heavy metals as well as organic contaminants. Testing of a bench-scale unit is currently underway.

UW-Madison has tested its photocatalytic reactor at the laboratory scale on aqueous solutions of several organic contaminants, including polychlorinated biphenyls, chlorosalicylic acid, salicylic acid, and ethylenediamine tetraacetate. UW-Madison has also used similar reactors to remove volatile organic compounds, such as trichloroethene, tetrachloroethene, benzene, and ethylene from air streams. Photooxidation of trichloroethene and tetrachloroethene has been successfully field-tested at low flow rates (less than 0.1 standard cubic feet per minute).

## FOR FURTHER INFORMATION:

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**UV TECHNOLOGIES, INC.**  
**(formerly Energy and Environmental Engineering, Inc.)**  
**(UV CATOX™ Process)**

**TECHNOLOGY DESCRIPTION:**

The UV CATOX™ process photochemically oxidizes organic compounds in wastewater using hydrogen peroxide, a chemical oxidant, ultraviolet (UV) radiation, and a photocatalyst. The photochemical reaction has the potential to reduce high concentrations (200,000 or more parts per million [ppm]) of organics in water to nondetectable levels. The energy from UV radiation is predominantly absorbed by the organic compound and the oxidant, making both species reactive. The process can be used as a final treatment step to reduce organic contamination in industrial wastewater and groundwater to acceptable discharge limits.

The existing bench-scale system treats solutions containing up to several thousand ppm of total organic carbon at a rate of 3 gallons per minute. The bench-scale system consists of a photochemical reactor, where oxidation occurs, and associated tanks, pumps, and controls. The UV lamps are high-intensity lamps that penetrate the wastewater more effectively. The portable, skid-mounted system's design depends on the chemical composition of the wastewater or groundwater being treated.

Typically, the contaminated wastewater is pumped through a filter unit to remove suspended particles. Next, the filtrate is mixed with stoichiometric quantities of hydrogen peroxide. Finally, this mixture is fed to the photochemical reactor and irradiated. Reaction products are carbon dioxide, water, and the appropriate halogen acid. Reaction kinetics depend on (1) contaminant concentration, (2) peroxide concentration, (3) irradiation dose, and (4) radiation spectral frequency.

**WASTE APPLICABILITY:**

The UV CATOX™ process treats industrial wastewater and groundwater containing organics at concentrations up to several thousand ppm. Destruction efficiencies greater than two orders of magnitude have been obtained for chlorobenzene, chlorophenol, and phenol, with low to moderate dose rates and initial concentrations of 200 ppm. Destruction efficiencies of three orders of magnitude have been demonstrated on simulated industrial waste streams representative of textile dyeing operations, with higher dose rates and an initial concentration of 200 ppm.

**STATUS:**

Studies of the UV CATOX™ process under the SITE Emerging Technology Program are complete, and the technology has been invited to participate in the SITE Demonstration Program. The Emerging Technology Report (EPA/540/SR-92/080), Emerging Technology Bulletin (EPA/540/F-92/004), and Emerging Technology Summary (EPA/540/SR-92/080) are available from EPA.

Work involving the on-line production of oxidants and the effectiveness of the photocatalytic substrate is underway under funding from EPA Small Business Industry Research Phase II and Phase I awards.

Representative results from recent trials using the UV CATOX™ process are summarized in the table below. Results are shown as the electric energy dose per gram-mole of initial contaminant to cause one decade of contaminant destruction.

Contaminant <sup>1)</sup>	Dose (kW-hr/ gmole/decade) <sup>2)</sup>
Chlorobenzene	7
Trichloroethene	5
Trichloroethane [500]	1
Tetrachloroethene	6
1,1,1-Trichloroethane	33
1,1,1-Trichloroethene [1,000]	7
Benzene, toluene, ethylbenzene, & xylene	5
Reactive Black Dye 5	26
Direct Yellow Dye 106	103
Direct Red Dye 83	31
Reactive Blue Dye 19	50
1-Chloronaphthalene [15]	27
Ethylene, diamine, & triacetic acid	17
Methanol	3
Textile waste (sulfur & indigo dyes) [740]	11
Textile waste (fiber reactive dyes) [270]	7
Chemical waste (formaldehyde & thiourea) [8,200]	1

<sup>1)</sup>All are 100 parts per million,  
except as noted

<sup>2)</sup> kilowatt-hour per gram-mole per decade

The technology has been improved since the EPA reports were published. These improvements include (1) using the UV lamp as the energy source; (2) improving the photochemical reactor design; (3) improving the lamp design, including lamp intensity and spectral characteristics; and (4) fixing the catalyst.

A cost-competitive UV CATOX™ system can be designed and built to treat industrial wastewater with contaminant levels of 10 to 10,000 ppm.

## FOR FURTHER INFORMATION:

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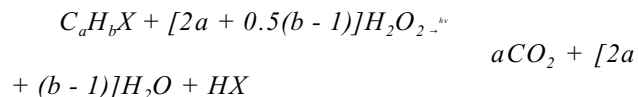
**UV TECHNOLOGIES, INC.**  
**(formerly Energy and Environmental Engineering, Inc.)**  
**(UV CATOX™ Process)**

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The existing bench-scale system treats solutions containing up to several thousand ppm of total organic carbon at a rate of 3 gallons per minute. The bench-scale system consists of a photochemical reactor, where oxidation occurs, and associated tanks, pumps, and controls. The UV lamps are high-intensity lamps that penetrate the wastewater more effectively. The portable, skid-mounted system's design depends on the chemical composition of the wastewater or groundwater being treated.

Typically, the contaminated wastewater is pumped through a filter unit to remove suspended particles. Next, the filtrate is mixed with stoichiometric quantities of hydrogen peroxide. Finally, this mixture is fed to the photochemical reactor and irradiated. The overall reaction is as follows:



where  $C_aH_bX$  represents a halogenated contaminant in the aqueous phase. Reaction products are carbon dioxide, water, and the appropriate halogen acid. Reaction kinetics depend on (1) contaminant concentration, (2) peroxide concentration, (3) irradiation dose, and (4) radiation spectral frequency.

**WASTE APPLICABILITY:**

The UV CATOX™ process treats industrial wastewater and groundwater containing organics at concentrations up to several thousand ppm. Destruction efficiencies greater than two orders of magnitude have been obtained for chlorobenzene, chlorophenol, and phenol, with low to moderate dose rates and initial concentrations of 200 ppm. Destruction efficiencies of three orders of magnitude have been demonstrated on simulated industrial waste streams representative of textile dyeing operations, with higher dose rates and an initial concentration of 200 ppm.

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except as noted

\*\* kilowatt-hour per gram-mole per decade

A cost-competitive UV CATOX™ system can be designed and built to treat industrial wastewater with contaminant levels of 10 to 10,000 ppm.

## FOR FURTHER INFORMATION:

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The technology has been improved since the EPA reports were published. These improvements include (1) using the UV lamp as the energy source; (2) improving the photochemical reactor design; (3) improving the lamp design, including lamp intensity and spectral characteristics; and (4) fixing the catalyst.

## VORTEC CORPORATION (Oxidation and Vitrification Process)

### TECHNOLOGY DESCRIPTION:

Vortec Corporation (Vortec) has developed an oxidation and vitrification process for remediating soils, sediments, sludges, and industrial wastes contaminated with organics, inorganics, and heavy metals. The process can oxidize and vitrify materials introduced as dry granulated materials or slurries.

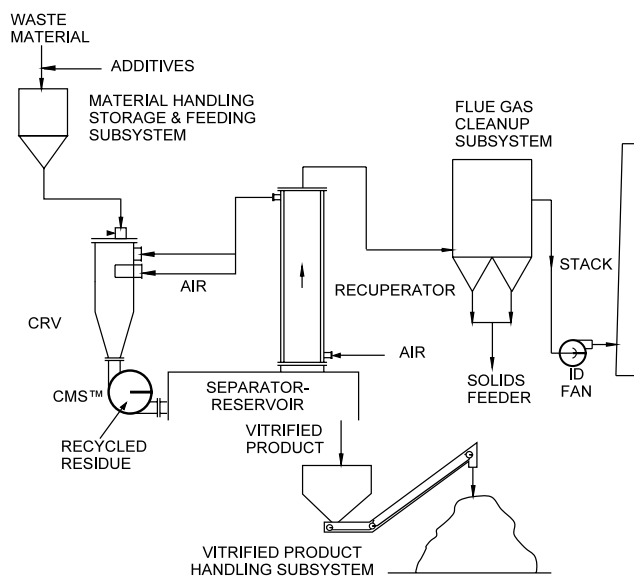
The figure below illustrates the Vortec oxidation and vitrification process. Its basic elements include (1) a cyclone melting system (CMS<sup>®</sup>); (2) a material handling, storage, and feeding subsystem; (3) a vitrified product separation and reservoir assembly; (4) a waste heat recovery air preheater (recuperator); (5) an air pollution control subsystem; and (6) a vitrified product handling subsystem.

The Vortec CMS<sup>®</sup> is the primary waste processing system and consists of two major assemblies: a counterrotating vortex (CRV) in-flight suspension preheater and a cyclone melter. First, slurried or dry-contaminated soil is introduced into the CRV. The CRV (1) uses the auxiliary fuel introduced directly into the CRB; (2) preheats the suspended waste

materials along with any glass-forming additives mixed with soil; and (3) oxidizes any organic constituents in the soil/waste. The average temperature of materials leaving the CRV reactor chamber is between 2,200 and 2,800°F, depending on the melting characteristics of the processed soils.

The preheated solid materials exit the CRV and enter the cyclone melter, where they are dispersed to the chamber walls to form a molten glass product. The vitrified, molten glass product and the exhaust gases exit the cyclone melter through a tangential exit channel and enter a glass- and gas-separation chamber.

The exhaust gases then enter an air preheater for waste heat recovery and are subsequently delivered to the air pollution control subsystem for particulate and acid gas removal. The molten glass product exits the glass- and gas-separation chamber through the tap and is delivered to a water quench assembly for subsequent disposal.



Vortec Vitrification Process

Unique features of the Vortec oxidation and vitrification process include the following:

- Processes solid waste contaminated with both organic and heavy metal contaminants
- Uses various fuels, including gas, oil, coal, and waste
- Handles waste quantities ranging from 5 tons per day to more than 400 tons per day
- Recycles particulate residue collected in the air pollution control subsystem into the CMS<sup>®</sup>. These recycled materials are incorporated into the glass product, resulting in zero solid waste discharge.
- Produces a vitrified product that is nontoxic according to EPA toxicity characteristic leaching procedure (TCLP) standards. The product also immobilizes heavy metals and has long-term stability.

### **WASTE APPLICABILITY:**

The Vortec oxidation and vitrification process treats soils, sediments, sludges, and heavy metal contamination. The high temperatures in the CRV successfully oxidize organic materials included with the waste. The inorganic constituents in the waste material determine the amount and type of glass-forming additives required to produce a vitrified product. This process can be modified to produce a glass cullet that consistently meets TCLP requirements.

### **STATUS:**

The Vortec oxidation and vitrification process was accepted into the SITE Emerging Technology Program in May 1991. Research under the Emerging Technology Program was completed in winter 1994, and Vortec was invited to participate in the SITE Demonstration Program.

A 50-ton-per-day system has been purchased by Ormet Aluminum Corporation of Wheeling, West Virginia for recycling aluminum spent pot liners, a cyanide- and fluoride-containing waste (K088). The recycling system became operational in 1996.

The Vortec CMS<sup>®</sup> is classified by the U.S. EPA as Best Demonstrated Available Technology (BDAT) for the processing of K088 waste. Additional projects with the aluminum industry and other industrial waste generators are in progress.

A 25-ton-per-day, transportable system for treating contaminated soil at a Department of Energy site in Paducah, Kentucky was delivered in 1999.

Vortec is offering commercial systems and licenses for the CMS<sup>®</sup> system.

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## WESTERN PRODUCT RECOVERY GROUP, INC. (Coordinate, Chemical Bonding, and Adsorption Process)

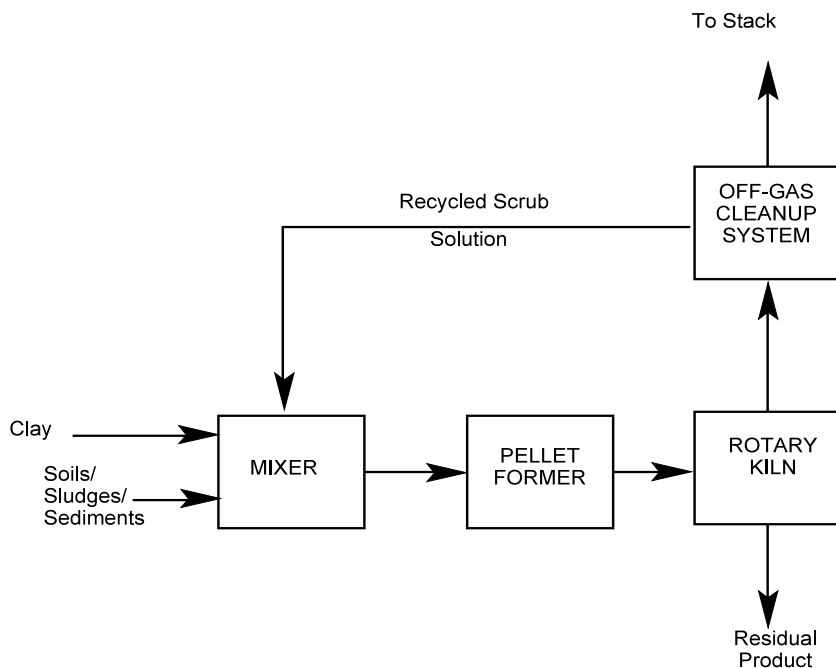
### TECHNOLOGY DESCRIPTION:

The coordinate, chemical bonding, and adsorption (CCBA) process converts heavy metals in soils, sediments, and sludges to nonleaching silicates. The process can also oxidize organics in the waste stream and incorporate the ash into the ceramic pellet matrix (see figure below). The solid residual consistency varies from a soil and sand density and size distribution to a controlled size distribution ceramic aggregate form. The residue can be placed back in its original location or used as a substitute for conventional aggregate. The process uses clays with specific cation exchange capacity as sites for physical and chemical bonding of heavy metals to the clay.

The process is designed for continuous flow. The input sludge and soil stream are carefully ratioed with specific clays and then mixed in a high-intensity mechanical mixer. The mixture is then densified and formed into green or unfired pellets of a desired size. The green pellets are then direct-fired in a rotary kiln

for approximately 30 minutes. The pellet temperature slowly rises to 2,000°F, converting the fired pellet to the ceramic state. Organics on the pellet's surface are oxidized, and organics inside the pellet are pyrolyzed as the temperature rises. As the pellets reach 2,000°F, the available silica sites in the clay chemically react with the heavy metals in the soil and sludge to form the final metal silicate product.

The process residue is an inert ceramic product, free of organics, with metal silicates providing a molecular bonding structure that precludes leaching. The kiln off-gas is processed in an afterburner and wet scrub system before it is released into the atmosphere. Excess scrub solution is recycled to the front-end mixing process.



Coordinate, Chemical Bonding, and Adsorption (CCBA) Process

## **WASTE APPLICABILITY:**

The CCBA process has been demonstrated commercially on metal hydroxide sludges at a throughput of 70 wet tons per month, based on an 8-hour day, for a 25 percent solid feed. This process can treat wastewater sludges, sediments, and soils contaminated with most mixed organic and heavy metal wastes.

## **STATUS:**

The CCBA process was accepted into the SITE Emerging Technology Program in January 1991. Under this program, the CCBA technology has been modified to include soils contaminated with both heavy metals and most organics. The SITE studies were completed at a pilot facility with a capacity of 10 pounds per hour. Proof tests using contaminated soil have been completed. The Emerging Technology Report, Emerging Technology Summary, and Emerging Technology Bulletin are available from EPA.

## **FOR FURTHER INFORMATION:**

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## WESTERN RESEARCH INSTITUTE (Contained Recovery of Oily Wastes)

### TECHNOLOGY DESCRIPTION:

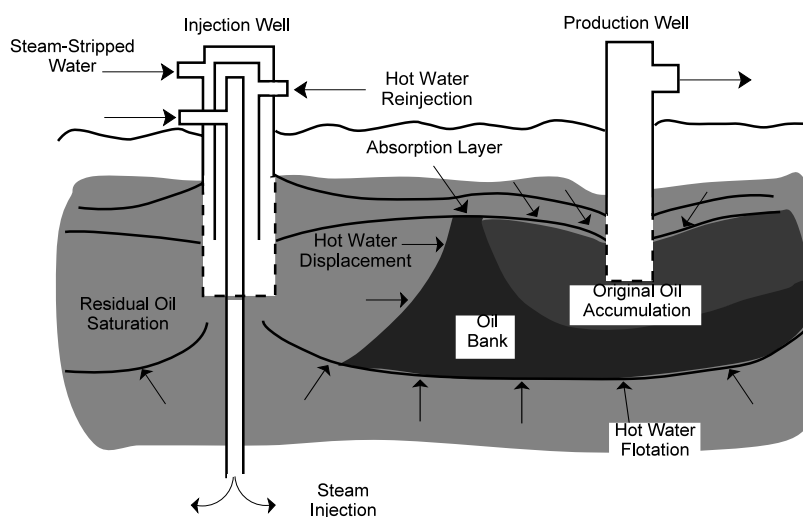
The contained recovery of oily wastes (CROW<sup>®</sup>) process recovers oily wastes from the ground by adapting a technology used for secondary petroleum recovery and primary production of heavy oil and tar sand bitumen. Steam or hot water displacement, with or without the use of chemicals such as surfactants or mobility control chemicals, moves accumulated oily wastes and water to production wells for aboveground treatment.

Injection and production wells are first installed in soil contaminated with oily wastes (see figure below). If contamination has penetrated into or below the aquifer, low-quality steam can be injected below the organic liquids to dislodge and sweep them upward into the more permeable aquifer soil regions. Hot water is injected above the impermeable regions to heat and mobilize the oily waste accumulation. The mobilized wastes are then recovered by hot water displacement.

When the organic wastes are displaced, organic liquid saturation in the subsurface pore space increases, forming a free-fluid bank. The hot water injection displaces the free-fluid bank to the production well. Behind the free-fluid bank, the contaminant saturation is reduced to an immobile residual saturation in the subsurface pore space. The extracted contaminant and water are treated for reuse or discharge.

During treatment, all mobilized organic liquids and water-soluble contaminants are contained within the original boundaries of waste accumulation. Hazardous materials are contained laterally by groundwater isolation and vertically by organic liquid flotation. Excess water is treated in compliance with discharge regulations.

The CROW<sup>®</sup> process removes the mobile portions of contaminant accumulations; stops the downward and lateral migration of organic contaminants; immobilizes any remaining organic wastes as a residual saturation; and reduces the volume, mobility, and toxicity of the



CROW<sup>®</sup> Subsurface Development

contaminants. The process can be used for shallow and deep areas, and can recover light and dense nonaqueous phase liquids. The system uses readily available mobile equipment. Contaminant removal can be increased by adding small quantities of selected biodegradable chemicals in the hot water injection.

In situ biological treatment may follow the displacement, which continues until groundwater contaminants are no longer detected in water samples from the site.

### **WASTE APPLICABILITY:**

The CROW<sup>®</sup> process can be applied to manufactured gas plant sites, wood-treating sites, petroleum-refining facilities, and other areas with soils and aquifers containing light to dense organic liquids such as coal tars, pentachlorophenol (PCP) solutions, chlorinated solvents, creosote, and petroleum by-products. Depth to the contamination is not a limiting factor.

### **STATUS:**

The CROW<sup>®</sup> process was tested in the laboratory and at the pilot-scale level under the SITE Emerging Technology Program (ETP). The process demonstrated the effectiveness of hot water displacement and the benefits of including chemicals with the hot water. Based on results from the ETP, the CROW<sup>®</sup> process was invited to participate in the SITE Demonstration Program. The process was demonstrated at the Pennsylvania Power and Light (PP&L) Brodhead Creek Superfund site at Stroudsburg, Pennsylvania.

The site contained an area with high concentrations of by-products from past operations. The demonstration began in July 1995; field work was completed in June 1996. Closure of the site was completed in late 1998.

The CROW<sup>®</sup> process was applied to a tar holder at a former MGP site in Columbia, Pennsylvania. The work was completed in 1998.

A pilot-scale demonstration was completed at an active wood treatment site in Minnesota. Over 80 percent of nonaqueous-phase liquids were removed in the pilot test, as predicted by treatability studies, and PCP concentrations decreased 500 percent. The full-scale, multiphase remediation is presently underway. Results indicate that organic removal is greater than twice that of pump-and-treat. The project is operating within the constraints of an active facility.

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## **ZENON ENVIRONMENTAL INC.**

### **(Cross-Flow Pervaporation System)**

#### **TECHNOLOGY DESCRIPTION:**

The ZENON Environmental Inc. (ZENON), cross-flow pervaporation technology is a membrane-based process that removes volatile organic compounds (VOC) from aqueous matrices. The technology uses an organophilic membrane made of nonporous silicone rubber, which is permeable to organic compounds, and highly resistant to degradation.

In a typical field application, contaminated water is pumped from an equalization tank through a prefilter to remove debris and silt particles, and then into a heat exchanger that raises the water temperature to about 165°F (75°C). The heated water then flows into a pervaporation module containing the organophilic membranes. The composition of the membranes causes organics in solution to adsorb to them. A vacuum applied to the system causes the organics to diffuse through the membranes and move out of the pervaporation module. This material is then passed through a condenser generating a highly concentrated liquid called permeate. Treated water exits the pervaporation module and is discharged from the system. The permeate separates into aqueous and organic phases. Aqueous phase permeate is sent back

to the pervaporation module for further treatment, while the organic phase permeate is discharged to a receiving vessel.

Because emissions are vented from the system downstream of the condenser, organics are kept in solution, thus minimizing air releases. The condensed organic materials represent only a small fraction of the initial wastewater volume and may be subsequently disposed of at significant cost savings. This process may also treat industrial waste streams and recover organics for later use.

#### **WASTE APPLICABILITY:**

Pervaporation can be applied to aqueous waste streams such as groundwater, lagoons, leachate, and rinse waters that are contaminated with VOCs such as solvents, degreasers, and gasoline. The technology is applicable to the types of aqueous wastes treated by carbon adsorption, air stripping, and steam stripping.



**ZENON Cross-Flow Pervaporation System**

## **STATUS:**

This technology was accepted into the SITE Emerging Technology Program (ETP) in January 1989. The Emerging Technology Report (EPA/540/F-93/503), which details results from the ETP evaluation, is available from EPA. Based on results from the ETP, ZENON was invited to demonstrate the technology in the SITE Demonstration Program. A pilot-scale pervaporation system, built by ZENON for Environment Canada's Emergencies Engineering Division, was tested over a 2-year period (see photograph on previous page). During the second year, testing was carried out over several months at a petroleum hydrocarbon-contaminated site in Ontario, Canada.

A full-scale SITE demonstration took place in February 1995 at a former waste disposal area at Naval Air Station North Island in San Diego, California. The demonstration was conducted as a cooperative effort among EPA, ZENON, the Naval Environmental Leadership Program, Environment Canada, and the Ontario Ministry of Environment and Energy.

Organics were the primary groundwater contaminant at the site, and trichloroethene (TCE) was selected as the contaminant of concern for the demonstration. The Demonstration Bulletin (EPA/540/MR- 95/511) and Demonstration Capsule (EPA/540/R-95/511a) are available from EPA.

## **DEMONSTRATION RESULTS:**

Analysis of demonstration samples indicate that the ZENON pervaporation system was about 98 percent effective in removing TCE from groundwater. The system achieved this removal efficiency with TCE influent concentrations of up to 250 parts per million at a flow rate of 10 gallons per minute (gpm) or less. Treatment efficiency remained fairly consistent throughout the demonstration; however, the treatment efficiency decreased at various times due to mineral scaling problems.

## **FOR FURTHER INFORMATION:**

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**EARTH TECH, INC.**  
**(formerly ITT Night Vision)**  
**(In Situ Enhanced Bioremediation of Groundwater)**

**TECHNOLOGY DESCRIPTION:**

ITT Night Vision is conducting in situ enhanced aerobic bioremediation of contaminated groundwater in fractured bedrock utilizing technologies developed at the U.S. Department of Energy Savannah River Site. The site demonstration involved remediation of groundwater in the vicinity of one contaminant source area as a pilot-scale operation, with the possibility of applying the technology elsewhere on site. Contaminants of concern in on-site groundwater included chlorinated solvents and their products, plus acetone and isopropanol. To accelerate the intrinsic (natural) biodegradation observed at the site, the selected remedy involves the subsurface injection of air, gaseous-phase nutrients (triethyl phosphate and nitrous oxide), and methane. The amendments were added to stimulate existing microbial populations (particularly methanotrophs) so that they could more aggressively break down the contaminants of concern. Amendment delivery to the surface was accomplished through an injection well, and the injection zone of influence was confirmed using surrounding groundwater monitoring wells and soil vapor monitoring points.

The patented PHOSter™ process for injection of triethyl phosphate in a gaseous phase was licensed for use at this site as an integral element of the enhanced bioremediation operation. This technology maximizes the subsurface zone of influence of nutrient injection as compared to technologies injecting nutrients in liquid or slurry form. Monitoring of contaminant (and breakdown product) concentrations in groundwater and soil vapor, measurement of microbiological population density and diversity, and monitoring of nutrient concentrations and groundwater geochemical parameters provides feedback on system effectiveness. This in turn allows adjustments to be made in the sequencing and rate of delivery of air, nutrients, and methane in response to changing subsurface conditions.

**WASTE APPLICABILITY:**

The Enhanced In-Situ Bioremediation process is applicable for creating volatile organic compounds (VOCs) in groundwater that can be naturally biodegraded, including some hard to degrade chlorinated VOCs. The mixture of air and gaseous phase nutrients that is injected into the subsurface provides an aerobic environment for contaminant degradation. Toxic products resulting from anaerobic degradation of chlorinated solvents (e.g., vinyl chloride) may be broken down completely in this aerobic environment. The in-situ process is especially applicable for hydrogeologically complex sites where injected nutrient flow patterns are uncertain (i.e., in fractured bedrock gaseous phase nutrient injection is more likely to affect a larger area than liquid nutrient injection). The process is also applicable in situations where subsurface utilities limit or preclude the use of technologies requiring excavation.

The enhanced bioremediation system, currently being used in the ongoing RCRA corrective action interim measure at the ITT Night Vision facility, was accepted into the SITE program in 1997, (the demonstration was conducted March 1998 to August 1999) with system start up occurring in March of 1998. The technology had previously been approved by EPA Region 3 as an Interim Measure part of the facility's ongoing RCRA Corrective Action program.

Due to the positive performance of the technology during the SITE Demonstration project, the remediation system was expanded to address the entire contamination plume at the site. Demonstration results are shown in Table 1. Results were based on 28 baseline and 28 final samples for the four critical analytes are presented in Table 1. VOC concentrations were determined by EPA SW-846 Method 8260. The results indicate that the targeted 75 percent reduction was achieved or exceeded for two of the four critical compounds, from baseline to final events.

## FOR FURTHER INFORMATION:

Target Compound	Contaminant Concentration (µg/L)		Average Percent Reduction	Statistically Significance Present Reduction
	Baseline	Final		
CA	256	210	36	4
1,1-DCA	960	190	80	71
<i>cis</i> -1,2-DCE	1,100	90	97	55
VC	1,100	45	96	52

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## **ELECTRO-PETROLEUM, INC.**

### **(Electro-Kinetically Aided Remediation [EKAR])**

#### **TECHNOLOGY DESCRIPTION:**

Electrokinetics is a general term describing a variety of physical changes, electrochemical reactions and coupled flows, which can occur when electrical current flows through soils containing one or more phases of fluids. Electrokinetically-Aided Remediation (EKAR), which utilizes electric fields to drive fluids and charged particles through a porous medium, is being developed for in-situ soil remediation. In this process, an electrical current or potential difference is applied across electrodes placed into soil in the treatment area. The applied electrical current effectively enlarges the throat diameter of soil pores, compared to Darcy flow, and changes the capillary forces allowing NAPL to pass through. Dissolved organic and non-aqueous phase liquids (NAPLs) will also accompany the increased electroosmotic water flux toward the cathode. Hydrolyzed ionic species and charged colloidal particles will drift toward the electrode of opposite polarity.

A typical electrokinetic field deployment is set up as follows: A seven-spot pattern consisting of six anode wells surrounding a central cathode extraction well is used to remediate a volume of subsurface material. NAPL concentrations are extracted at the electrode wells for further treatment or disposal. The mobility of the ions and pore fluids decontaminates the soil mass. EKAR can supplement or replace conventional pump and treat technologies.

#### **WASTE APPLICABILITY:**

Electrokinetically aided remediation has particular applicability to both organic and inorganic contaminants in low permeability soils. Electrokinetic mechanisms increase fluid flow through fine grained porous media. This mechanism increases the removal of mobile non-aqueous phase liquid, its residual, and its aqueous phases. It is equally effective with both LNAPL and DNAPL. Because of the electrokinetically imposed electric field's ability to drive charged particles through a fluid, the technology can be used to increase particulate contaminant flux through soil and transport microbes to contaminated zones for bioremediation. Electrochemical treatment may be engineered to extract soluble species of cations and anions without the need for water flushing and secondary treatments.

#### **STATUS:**

Bench laboratory studies investigating the metals, organics, and radionuclides, have been completed. Organics investigated included acetone, BTEX, and PAHs. Metals removal investigations focused on arsenic, cadmium, chromium, lead, nickel and mercury.

Radionuclides investigated included cesium, cobalt, technetium, strontium, and uranium. Bench scale treatability tests have shown significant removal of TCE from core samples.

The technology is scheduled to be demonstrated at Offut Air Force Base, Nebraska in 2003, and evaluated for its ability to remediate TCE contaminated soils.

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**HARDING ESE, A MACTEC COMPANY**  
(formerly ABB Environmental Services, Inc.)  
(Two-Zone, Plume Interception, In Situ Treatment Strategy)

**TECHNOLOGY DESCRIPTION:**

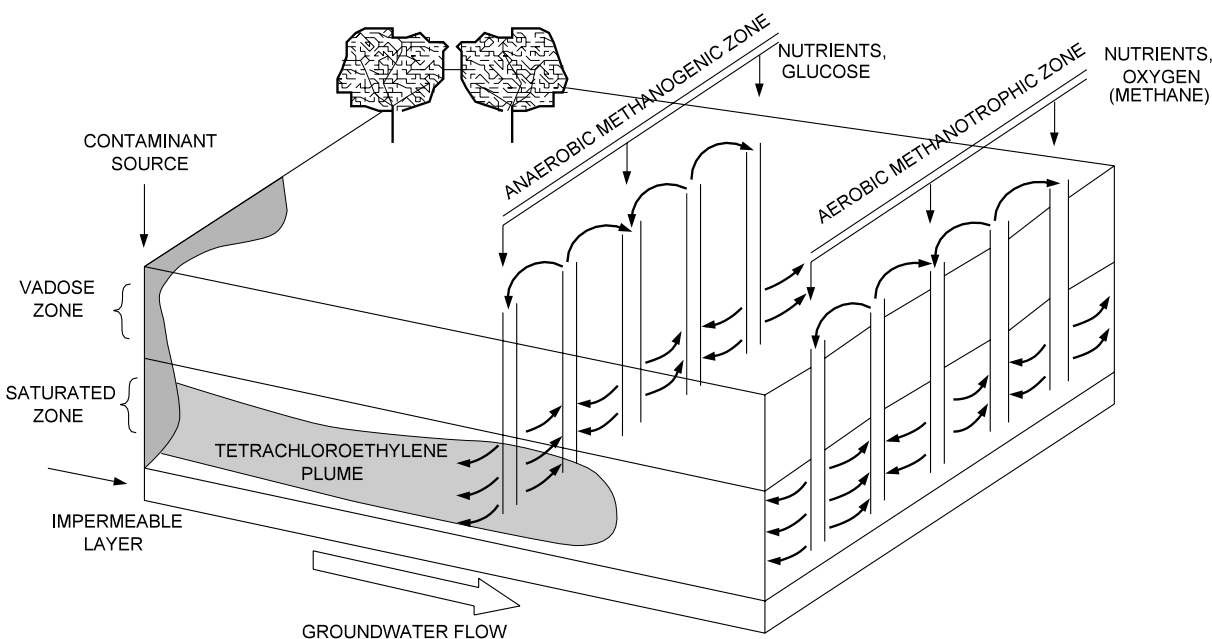
The two-zone, plume interception, in situ treatment strategy is designed to treat chlorinated and nonchlorinated organic compounds in saturated soils and groundwater using a sequence of anaerobic and aerobic conditions (see figure below). The in situ anaerobic and aerobic system constitutes a treatment train that biodegrades a wide assortment of chlorinated and nonchlorinated compounds.

When applying this technology, anaerobic and aerobic conditions are produced in two distinct, hydraulically controlled, saturated soil zones. Groundwater passes through each zone as it is recirculated through the treatment area. The first zone, the anaerobic zone, is designed to partially dechlorinate highly chlorinated solvents such as tetrachloroethene (PCE), trichloroethene (TCE), and 1,1,1-trichloroethane with natural biological processes. The second zone, the

aerobic zone, is designed to biologically oxidize the partially dechlorinated products from the first zone, as well as other compounds that were not susceptible to the anaerobic treatment phase.

Anaerobic conditions are produced or enhanced in the first treatment zone by introducing a primary carbon source, such as lactic acid, and mineral nutrients, such as nitrogen and phosphorus. When proper anaerobic conditions are attained, the target contaminants are reduced. For example, PCE is dechlorinated to TCE, and TCE is dechlorinated to dichloroethene (DCE) and vinyl chloride. Under favorable conditions, this process can completely dechlorinate the organics to ethene and ethane.

Aerobic conditions are produced or enhanced in the second treatment zone by introducing oxygen, mineral nutrients such as nitrogen and phosphorus, and possibly an additional carbon source, such as methane



Two-Zone, Plume Interception, In Situ Treatment Strategy

(if an insufficient supply of methane results from the pstream, anaerobic zone). When proper aerobic conditions are attained in this zone, partially dechlorinated products and other target compounds from the first zone are oxidized. For example, less-chlorinated ethenes such as DCE and vinyl chloride are cometabolized during the aerobic microbiological degradation of methane.

The treatment strategy is designed to biologically remediate subsoils by enhancing indigenous microorganism activity. If indigenous bacterial populations do not provide the adequate anaerobic or aerobic results, specially adapted cultures can be introduced to the aquifer. These cultures are introduced using media-filled trenches that can support added microbial growth.

### **WASTE APPLICABILITY:**

The two-zone, plume interception, in situ treatment strategy is designed to treat groundwater and saturated soils containing chlorinated and nonchlorinated organic compounds.

### **STATUS:**

The two-zone, plume interception, in situ treatment strategy was accepted into the SITE Emerging Technology Program in July 1989. Optimal treatment parameters for field testing were investigated in bench-scale soil aquifer simulators. The objectives of bench-scale testing were to (1) determine factors affecting the development of each zone, (2) evaluate indigenous bacterial communities, (3) demonstrate treatment of chlorinated and nonchlorinated solvent mixtures, and (4) develop a model for the field remediation design. The Emerging Technology Bulletin (EPA/540/F-95/510), which details the bench-scale testing results, is available from EPA.

A pilot-scale field demonstration system was installed at an industrial facility in Massachusetts. Pilot-scale testing began in September 1996. Results from this testing indicate the following:

- The reductive dechlorination of PCE and TCE to DCE, VC, and ethene has been accomplished primarily by sulfate-reducing bacteria.
- A time lag of about 4 months was required before significant reductive dechlorination occurred. This corresponded to the time and lactic acid dosing required to reduce the redox to about -100 throughout the treatment cell.
- Sequential anaerobic-aerobic (Two-Zone) biodegradation of PCE and its degradation products appear to be a viable and cost-effective treatment technology for the enhancement of natural reductive dechlorination processes.

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**LEWIS ENVIRONMENTAL SERVICES, INC./  
HICKSON CORPORATION**  
**(Chromated Copper Arsenate Soil Leaching Process)**

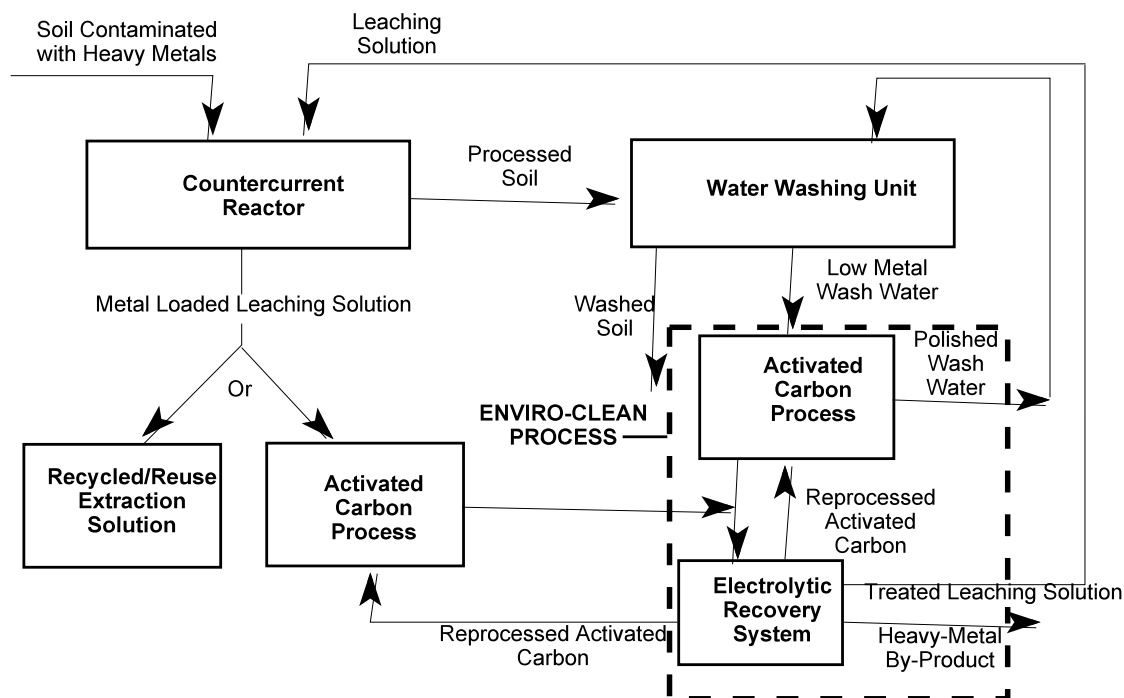
**TECHNOLOGY DESCRIPTION:**

Lewis Environmental Services, Inc. (Lewis), has developed a soil leaching process to remediate soils contaminated with inorganics and heavy metals including chromium, copper, cadmium, mercury, arsenic, and lead.

The soil leaching process consists of leaching contaminated soil in a countercurrent stirred reactor system (see figure below). A screw feeder delivers the soil into the reactor, where it is leached with sulfuric acid for 30 to 60 minutes. The sulfuric acid solubilizes the inorganics and heavy metals into the leaching solution. Any organic contaminants are separated and

decanted from the leaching solution, using strong acid leachate, space separation, and skimming. The processed soil is then washed with water and air-dried.

The wash water is then treated with Lewis' ENVIRO-CLEAN PROCESS, which consists of a granulated activated carbon system followed by an electrolytic recovery system. The ENVIRO-CLEAN PROCESS recovers the heavy metals from the leaching solution and wash water and produces an effluent that meets EPA discharge limits for heavy metals. The treated wash water can then be reused in the soil washing step. The leaching solution can be returned directly to the stirred reactor system, depending on its metals concentration.



Chromated Copper Arsenate Soil Leaching Process

Contaminated soil must be properly sized and screened to facilitate leaching in the stirred reactor system. Large pieces of debris such as rocks, wood, and bricks must be removed before treatment. Standard screening and classification equipment, such as that used in municipal waste treatment plants, is suitable for this purpose.

The soil leaching process does not generate appreciable quantities of treatment by-products or waste streams containing heavy metals. The treated soil meets toxicity characteristic leaching procedure (TCLP) criteria and can be either returned to the site or disposed of at a nonhazardous landfill. The granular activated carbon requires disposal after about 20 to 30 treatment cycles and should also meet TCLP criteria. Heavy metals recovered by the ENVIRO-CLEAN process can be reused by industry.

### **WASTE APPLICABILITY:**

The soil leaching process can treat wastes generated by the wood preserving and metal plating industries, battery waste sites, and urban lead sites.

### **STATUS:**

The soil leaching process was accepted into the Emerging Technology Program in 1993. Laboratory-scale tests have shown that the process successfully treats soil contaminated with chromated copper arsenate (CCA). The evaluation of the technology under the SITE Program was completed in September 1996. Results from the evaluation will be available in 1997.

In 1992, Lewis treated a 5-gallon sample of CCA-contaminated soil from Hickson Corporation (Hickson), a major CCA chemical manufacturer. The treated soil met TCLP criteria, with chromium and arsenic, the two main leaching solution constituents, averaging 0.8 milligram per kilogram (mg/kg) and 0.9 mg/kg, respectively.

Analysis also revealed 3,330 milligrams per liter (mg/L) of chromium, 13,300 mg/L of copper, and 22,990 mg/L of iron in the leaching solution. In addition, analysis indicated 41.4 mg/L of chromium, 94.8 mg/L of copper, and 3.0 mg/L of arsenic present in the wash water. After treatment, the wash water contained metals levels below 0.01 mg/L for copper and chromium and 0.3 mg/L for arsenic.

Lewis plans further laboratory-scale testing at its Pittsburgh, Pennsylvania facility, followed by bench- or pilot-scale testing at Hickson's facility in Conley, Georgia.

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## MATRIX PHOTOCATALYTIC INC. (Photocatalytic Air Treatment)

### TECHNOLOGY DESCRIPTION:

Matrix Photocatalytic Inc. is developing a titanium dioxide (TiO<sub>2</sub>) photocatalytic air treatment technology that destroys volatile organic compounds (VOC) and semivolatile organic compounds in air streams. During treatment, contaminated air at ambient temperatures flows through a fixed TiO<sub>2</sub> catalyst bed activated by ultraviolet (UV) light. Typically, organic contaminants are destroyed in fractions of a second.

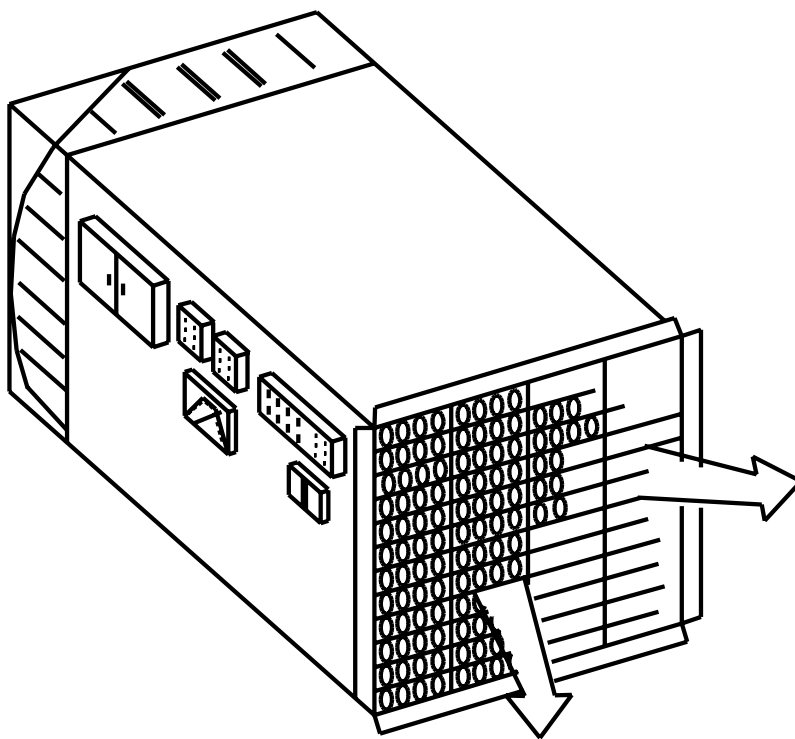
Technology advantages include the following:

- Robust equipment
- No residual toxins
- No ignition source
- Unattended operation
- Low direct treatment cost

The technology has been tested on benzene, toluene, ethylbenzene, and xylene; trichloroethene; tetrachloroethane; isopropyl alcohol; acetone; chloroform; methanol; and methyl ethyl ketone. A field-scale system is shown in the photograph on the next page.

### WASTE APPLICABILITY:

The TiO<sub>2</sub> photocatalytic air treatment technology can effectively treat dry or moist air. The technology has been demonstrated to purify contaminant steam directly, thus eliminating the need to condense. Systems of 100 cubic feet per minute have been successfully tested on vapor extraction operations, air stripper emissions, steam from desorption processes, and VOC emissions from manufacturing facilities. Other potential applications include odor removal,



Full-Scale Photocatalytic Air Treatment System

stack gas treatment, soil venting, and manufacturing ultra-pure air for residential, automotive, instrument, and medical needs. Systems of up to about 1,000 cubic feet per minute can be cost- competitive with thermal destruction systems.

### **STATUS:**

The TiO<sub>2</sub> photocatalytic air treatment technology was accepted into SITE Emerging Technology Program (ETP) in October 1992; the evaluation was completed in 1993. Based on results from the ETP, this technology was invited to participate in the SITE Demonstration Program. For further information about the evaluation under the ETP, refer to the journal article (EPA/600/A-93/282), which is available from EPA. A suitable demonstration site is being sought.

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## PROCESS TECHNOLOGIES INCORPORATED (Photolytic Destruction of Vapor-Phase Halogens)

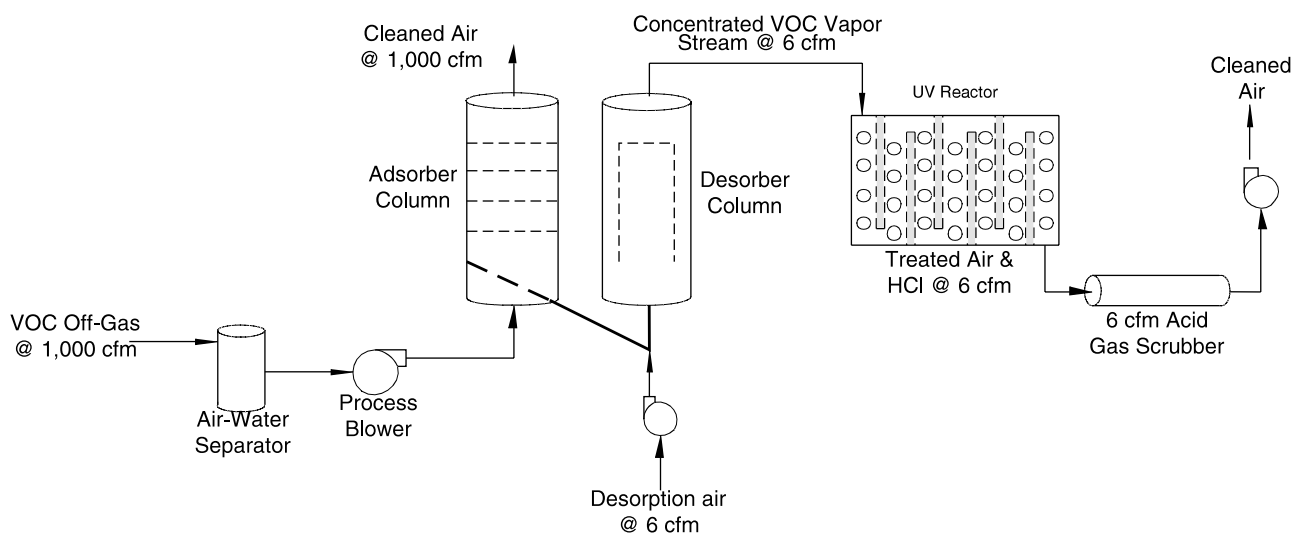
### TECHNOLOGY DESCRIPTION:

The proprietary, nonthermal technology developed by Process Technologies Incorporated (PTI), is a method of photochemically oxidizing gaseous organic compounds within a reaction chamber. PTI's Photolytic Destruction Technology (PDT) uses low-pressure ultraviolet (UV) lamps, with UV emissions primarily at wavelengths in the 185 to 254 nanometer range, located within the reaction chamber. Photons emitted from these lamps break apart the chemical bonds making up the volatile organic compound (VOC) molecule. The process is capable of destroying mixtures of chlorinated and nonchlorinated VOCs.

The PDT system is designed and fabricated in 3- to 12-cubic-feet-per-minute (cfm) modules. The size of the module applied is dependent on the gas flow rate and VOC concentrations in the gas stream. PTI implements a fluid bed concentrator to allow for the treatment of high flow gas streams, or those with rates greater than 1,000 cfm. Significant cost savings can be realized if the gas flow can be reduced, and concentration increased prior to destruction.

PTI uses a proprietary reagent that forms a liner within the process chamber. The reagent reacts chemically with the gaseous degradation products formed during the photolytic destruction of halocarbon molecules to form solid, stable reaction products.

Reagent lifetime depends on flow rate, influent concentrations, and specific chemical composition of destruction targets. PTI has performed tests on spent reagent to determine whether the material would be classified as a hazardous waste under federal regulations. Those tests indicated that the spent reagent is likely nontoxic. The spent reagent is also not reactive, corrosive, or flammable, and thus PTI is confident that it is not a hazardous waste under federal law. PTI accordingly believes that the spent reagent material can be disposed of as ordinary solid waste or used as a feedstock for cement manufacturing. The PTI process is simple in design and easy to operate. The system is designed to run continuously, 24-hours per day.



Simplified Process Flow Diagram  
of Photolytic Destruction

## WASTE APPLICABILITY:

The technology was developed to destroy a number of groups of compounds, including chlorinated solvents, c h l o r o f l u o r o c a r b o n s ( C F C s ), hydrochlorofluorocarbons (HCFCs), and halons. Example sources of process off-gas that contains chlorinated and nonchlorinated VOCs, CFCs, and HCFCs include steam vapor extraction, tank vents, air strippers, steam strippers, and building vent systems.

The process is capable of destroying as high as 50,000 parts per million by volume VOC streams. The system is capable of achieving greater than 90 percent on-line availability, inclusive of scheduled maintenance activities.

## STATUS:

The PTI technology was accepted into the SITE Demonstration Program in summer 1994. The demonstration began in September 1994 at McClellan Air Force Base (AFB) in Sacramento, California. The SITE demonstration was postponed shortly thereafter. Activities under the SITE Program were rescheduled in 1997. Additional tests incorporating an improved design for treating soil vapor extraction off-gas were successfully completed at the AFB in January 1996.

PTI completed a four month demonstration of the combined fluid bed concentrator and PDT system at the U.S. Navy's North Island Site 9 in February, 1998. This demonstration was performed to evaluate the effectiveness and cost to remove and destroy VOC vapor from an existing SVE system. The results of the demonstration at the Navy's North Island Site 9 showed the PTI System was capable of achieving greater than 95 percent destruction and removal efficiency of VOCs in the soil vapor at a 250 standard cfm flow rate. Furthermore, the Navy determined that the PTI System provided a 45 percent cost savings over activated carbon or flameless thermal oxidation.

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## SELENTEC ENVIRONMENTAL TECHNOLOGIES, INC. (Selentec MAG\*SEP<sup>SM</sup> Technology)

### TECHNOLOGY DESCRIPTION:

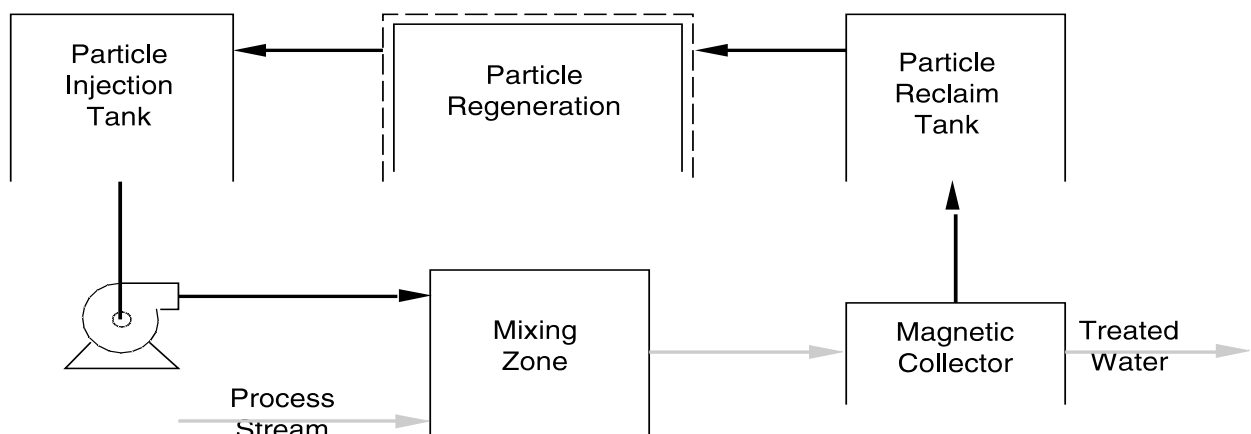
The MAG\*SEP<sup>SM</sup> process uses the principles of chemical adsorption and magnetism to selectively bind and remove heavy metals or radionuclides from aqueous solutions such as groundwater, wastewater, and drinking water. Contaminants are adsorbed on specially formulated particles which have a core made from magnetic material; these particles are then separated (along with the adsorbed contaminants) from the solution using a magnetic filter or magnetic collector. The magnetic core has no interaction with the contaminant.

The proprietary adsorbing particles are made of a composite of organic polymers and magnetite. The particles can be manufactured in two forms: one with an ion exchanger and/or chelating functional group attached to the particle surface (amidoxime functionalized resin), or one with inorganic adsorbers bound to the surface of the particles (clinoptilolite). These particles have high surface areas and rapid adsorption kinetics.

A typical MAG\*SEP<sup>SM</sup> treatment system consists of:

- a particle contact zone
- a particle handling system, including particle injection components, a magnetic separator, and particle reclaim components
- a particle regeneration system (where applicable)

The process stream enters a contact zone (usually a tank - other configurations are used for particular applications) where MAG\*SEP<sup>SM</sup> particles are injected and mixed. The contact zone provides the necessary solution flow characteristics and contact time with the particles to ensure that the contamination will be adsorbed onto the active surface sites of the particles. The mixture then flows through a magnetic collector, where the contaminated particles are retained while the treated process stream passes through (see figure below).



Schematic Diagram of the Mag\*SEP<sup>SM</sup> Treatment System

Depending on the application, type of particle, and contaminant concentration, the particles may be re-injected into the flow stream, collected and disposed of, or regenerated and reused. The regeneration solution is processed to recover (concentrate and remove) the contaminants and may be recycled.

The MAG\*SEP<sup>SM</sup> process is able to selectively remove (either ex situ or in situ) the following contaminants from aqueous solutions: titanium, copper, cadmium, arsenic, cobalt, molybdenum, platinum, selenium, chromium, zinc, gold, iodine, manganese, technetium, mercury, strontium, iron, ruthenium, thallium, cesium, cobalt, palladium, lead, radium, nickel, silver, bismuth, thallium, antimony, zirconium, radium, cerium, and all actinides. The process operates at flow rates up to 2,000 gallons per minute (gpm).

### **WASTE APPLICABILITY:**

The MAG\*SEP<sup>SM</sup> technology reduces heavy metal and radionuclide contamination in water and wastewater. The technology has specific applications in environmental remediation and restoration, treatment of acid mine drainage, resource recovery, and treatment of commercial industrial wastewater. MAG\*SEP<sup>SM</sup> particles can be produced to incorporate any known ion exchanger or sorbing material. Therefore, MAG\*SEP<sup>SM</sup> can be applied in any situation where conventional ion exchange is used.

### **STATUS:**

The MAG\*SEP<sup>SM</sup> technology was accepted into the SITE Program in 1996 and is also one of 10 technologies participating in the White House's Rapid Commercialization Initiative. In addition, in 1997 the MAG\*SEP<sup>SM</sup> technology received a Research and Development (R&D) 100 Award from the R&D trade publication as one of the 100 Most Technologically Significant New Products of 1997.

Selentec has completed a demonstration of the MAG\*SEP<sup>SM</sup> technology at the U.S. Department of Energy's Savannah River Site. Heavy metal concentrations in coal pile runoff water were significantly reduced to below drinking water standards. Another demonstration of the technology is planned for Savannah River whereby radioactive cesium will be removed streams. The technology is also being used to remove mercury from heavy water drums at Savannah River.

The first commercial unit of the MAG\*SEP<sup>SM</sup> technology was put into service on November 18, 1998, at a dairy in Ovruch, Ukraine. For this application, the unit is removing radioactive cesium from contaminated milk produced near the Chernobyl Nuclear Reactor Plant.

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